# SCALE, PATTERN, AND PROCESS IN BIOLOGICAL INVASIONS

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1997

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ACKNOWLEDGEMENTS

The work presented in this dissertation would not have been possible without the cooperation and encouragement of many. Foremost is the understanding of my immediate family, that is my wife Patty and now three-year-old son, Reece. Reece, while generally confused about what I was doing, nonetheless supported my effort to "write a book" in order to become a "doctor." Conflicts arose only when he needed my computer for dinosaur games. My co-advisors, W. M. Kitchens and C. S. Holling, encouraged my investigations and provided me with intellectual support and opportunity. For the same reasons, I extend my appreciation to my committee members, S. Humphrey, M. Moulton and D. Wojcik. Numerous friends and colleagues provided me with intellectual support and acted as a sounding board for ideas. Foremost are E. A. Forys, G. Peterson M. P. Moulton and J. Sendzemir as well as the entire "gang" of the Arthur Marshal Ecology Laboratory. I wish to thank all for their support and friendship.

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Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

SCALE, PATTERN, AND PROCESS IN BIOLOGICAL INVASIONS

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December 1997

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The phenomenon of biological invasion and extinction are central foci of the field of conservation biology. Extinctions decrease diversity, and the loss of ecological function following extinctions jeopardizes other species and the continued function of ecosystems, as well as the services that they provide. Invasions may increase local diversity, but this is at the loss of global diversity.

Much effort has been made to determine the processes underlying invasions and extinctions. This has primarily resulted in long lists of characteristics of invasive and declining species. These lists are usually generated by single species studies or studies of isolated communities, and have little predictive value. Similarly, the association between invasions and "disturbance" is so vague as to be of little value. Disturbance is a scale-bound measure, and association made between invasions and disturbance is of little value as long as it remains scale invariant.

Landscape pattern is scale dependent and different sized animals living upon the same landscape perceive their environment at different scales. Increasing evidence suggests that ecosystems are structured by relatively few key processes operating at specific temporal and spatial scales. The distinct temporal frequencies and spatial scale characterizing these key processes creates hierarchical landscape structures with scale specific pattern. The scale-specific effect of key processes leads to a discontinuous distribution of ecological structure and pattern which in turn entrains attributes of animals residing on the landscape. This entrainment reflects adaptations to a discontinuous pattern of resource distribution acting on animal community assembly and evolution both by sorting species and by providing a specific set of evolutionary opportunities and constraints and leads to a discontinuous distribution of animal body masses.

I tested several traditional hypotheses concerning invasions and extinctions. These hypotheses were based on body size, niche and phylogeny, and all were rejected. However, invasions and extinctions were predictable in the context of scale-specific community structure, and tended to occur at scale breaks. Additional biological variability at scale breaks was documented, including an association with abundance and nomadism. An understanding of the scale-specific nature of animals, ecological processes, and structure led to a hierarchical model of vertebrate community assembly.

# INTRODUCTION

Several years ago I was requested to find ten 200 to 400-hectare study areas that consisted of a single habitat-type and supported relatively homogenous populations of red imported fire ants (*Solenopsis invicta*), Northern Bobwhite (*Colinus virginianus*) and white-tailed deer (*Odocoileus virginianus*). It took but few trips to the landscape in question, covering tens of thousands of square kilometers, to reach the conclusion that such a task was not possible. Although the desired study area size was small and the broad landform extensive, ten sites supporting homogenous populations of those species could not be found. The eventual solution was to pair study sites to remove the inherent variability among sites.

Although now seemingly obvious, the reason for my difficulties were not apparent at the time. A fire ant colony may exploit an area of no more than 2,500 $m^2$ while a deer may operate in an area in the order of 1,000,000 $m^2$. Fire ants, bobwhite, and deer all exploit their environment at grossly different scales. What may be relatively homogenous habitat for bobwhite, and thus support comparable populations on 200-ha study areas, is too small to capture the repeated patterns in deer density, and too large for fire ants. Because these species differ greatly in body size, their environmental perception also is grossly different. The habitat structure that each

species perceives differs, and thus their pattern of spatial distribution also differs, although the landscape is the same at a very broad scale.

I have continued to study fire ants as a case study of the ecological impacts of non-indigenous species. The red imported fire ant is an ecologically disruptive non-indigenous species that has invaded most of the southeastern United States. As with many invasive species, the fire ant has been associated with "disturbed" habitats (Tschinkel 1988). One of the earliest recognized associations of invasive species was a predilection for disturbed habitats (Elton 1958). However, like many of the other suggested traits of invasive species and invaded habitats (see Chapter 1), the association with disturbed habitats has been implicitly scale-invariant. A disturbance large enough to be exploited by fire ants, for example the 1-$m^2$ spoil pile from mosquito-ditching operations, is far too small-scale for a larger invasive species such as an armadillo (*Dasypus novemcinctus*).

My goal for this document is to first briefly review traits of invasive species, test some of those suggested traits and discuss their shortcomings. Then I investigate invasions in a scale-specific context. Are the biological extremes of invasion and extinction understandable by viewing communities as distinct groupings of species that operate at different scales? By focusing on systems, and the scale-specific structure present in those systems, rather than single species, insight may be gained that otherwise would not be apparent.

Chapter 1 presents an overview of invasions and extinctions and quantitatively tests some of the traditional hypotheses and suggested traits of invasive and declining species. Chapter 2 investigates the relationships between landscape structure, scale-

specific assemblages of species, and the patterns of vertebrate invasion and extinction at the ecosystem level. Chapter 3 further tests the association of non-indigenous species with scale-specific vertebrate assemblages within self-similar landscapes. It does so by incorporating data rarely possible in the analysis of biological invasions, known unsuccessful introductions into a continental system. Chapter 4 investigates the changes in vertebrate community structure at the ecosystem level resulting from the addition of non-indigenous species and the loss of declining species: does community structure change following species' additions and deletions? In relation, I test whether the annual loss of avifauna species following migration results in changes in community structure, and whether migratory turnover is random or non-random in terms of ecosystem-level community structure. Chapter 5 tests whether ecosystems structured by similar processes but with dissimilar faunas exhibit similar vertebrate community structure. This is accomplished by comparing vertebrate community structure among mediterranean-climate ecosystems. Mediterranean-climate ecosystems also provide data for additional tests of the pattern of successful biological invasions in the context of vertebrate community structure. Chapter 6 provides additional tests of species' status in relation to vertebrate community structure. Specifically, this chapter uses data from mediterranean-climate ecosystems to further test if there is an association between rarity and vertebrate community structure, and tests for associations between abundance and nomadism and vertebrate community structure. Chapter 7 tests one of the propositions that link scale, biological diversity and abundance. Chapter 7 uses a null model and computer simulations to test for competitive structuring among animals using the same range of scale. I conclude by

summarizing and synthesizing the results of the earlier chapters and presenting a hierarchical model of community assembly that builds upon the results presented in the separate chapters.

# CHAPTER 1
# TRADITIONAL HYPOTHESES: INVASIONS AND EXTINCTIONS IN THE EVERGLADES ECOREGION

## Introduction

The state of Florida ranks only after California in the number of federally listed endangered and threatened vertebrate species present (Office of Technology Assessment 1993). The majority of these listed species occur within the southern third of the state. This is particularly significant because of the relative paucity of native vertebrate species in this region. Vertebrate species richness declines from north to south in Florida with decreasing habitat diversity (Means and Simberloff 1987). Some of the listed species (e.g., Bald Eagle, *Haliaeetus leucocephalus*) may be capable of recovery and eventual delisting; others, such as the Carolina Parakeet (*Conuropsis carolinensis*) are already extinct. The decline in the majority of endangered vertebrate species in south Florida is linked to habitat destruction and fragmentation (Humphrey 1992, Moler 1992). Most currently endangered species exist in small, fragmented populations from which recovery is unlikely.

Despite these extinctions, the number of vertebrate species in Florida has been increasing, due to the influx of exotic species. South Florida's seaports and airports handle large amounts of cargo and human immigrants, and also a diverse group of vertebrate fauna. Some of these animals are shipped purposely for pet-trade, tourist

attractions, or livestock; others are inadvertent imports (Loftus and Hernon 1984). Most of these species fail to reproduce in south Florida (Wilson and Porras 1983), but some are able to establish breeding populations. Survival for many species may be enhanced by south Florida's subtropical climate; many established exotic species may be from similar climates and may be "preadapted" to the environment of south Florida (Newsome and Noble 1986). Some of these non-indigenous species are having negative impacts on native species. For example, the feral cat (*Felis catus*) has increased predation pressure on many small mammals, birds, and reptiles (Churcher and Lawton 1987). The Cuban treefrog (*Osteopilus septentrionalis*) has been linked with the decline of some native hylids (Wilson and Porras 1983).

If habitat alteration continues, south Florida will experience more extinctions. Until dramatic changes in policy and enforcement occur, more non-indigenous species will become established. The effect these changes will have on the composition and structure of the future vertebrate fauna in south Florida is unknown. However, there are a number of hypotheses concerning which native species are most vulnerable to extinction, and which non-indigenous species are likely to be successful invaders. This chapter tests four non-exclusive hypotheses about community change related to endangered and exotic fauna.

Body-mass difference hypothesis

The future vertebrate communities will be composed of smaller species than the communities of the historic past or the present, because larger species are predicted to be more prone to extinction and smaller species are predicted to be better invaders. Species that are the largest members in their guilds or families (Leck 1979,

Pimm et al. 1989, Willis 1980), or that have high body mass in the community (Laurance 1991), are hypothesized to be extinction-prone because they require large areas for foraging, are more likely to be rare (Arita et al. 1990), and because they have lower fecundity than smaller animals (Laurance 1991). Species that have smaller body size may be more likely to be successful invaders because they are generally r-selected (Kitching 1986, Lodge 1993a, Lodge 1993b), more likely to be inadvertently introduced, and more likely to be human commensals (Myers 1986, Newsome and Noble 1986).

Diet difference hypothesis

The future community will be comprised of species more generalized in their diets and who feed at lower trophic levels. Invading species that have the capacity to occupy a wide potential niche (Arthington and Mitchell 1986, di Castri 1990) will be more likely to succeed in their new environment. Species that are highly specialized in their diet, foraging strategy, or behavior are more likely to face extinction when habitat is fragmented or altered (Ambuel and Temple 1983, Faaborg 1979). Carnivorous species generally require larger home ranges to meet their metabolic needs (McNab 1963), and are more likely to be affected by pesticides and other contaminants (Douthwaite 1992, Outridge and Scheuhammer 1993).

Species replacement hypothesis

The future vertebrate community will be similar to the community of the recent past with regard to species body size and niche-use. It is assumed non-indigenous species that succeed will be the ones that can fill the vacant niches of the extinct, or declining species (Lawton 1984). Because resources may be partitioned among

species on the basis of body size (Brown 1975, Brown and Maurer 1987), they will be replacing species of similar size. This hypothesis assumes that most non-indigenous species have become established after the decline of the endangered native species.

Phylogenetic hypothesis

Endangerment will disproportionately affect the largest member of a family or guild (Leck 1979, Pimm et al. 1989, Willis 1980). This hypothesis has been forwarded many times, in several forms. It is similar to the body-mass difference hypothesis, but concentrates on phylogenetic relationships rather than overall body size within a community.

## Methods

Three vertebrate taxonomic groups were investigated: reptiles and amphibians (herpetofauna), birds, and mammals. Species' distributions were determined from museum records (Allen, unpublished data), published accounts, and the Florida Breeding Bird Atlas (Kale et al. *in press*). Only species that had established breeding populations in the United States south Florida Everglades Ecoregion (Bailey 1983) counties of Broward, Collier, Dade, Hendry, Lee, Monroe, and Palm Beach were included in the analysis. Pelagic and primarily aquatic species were excluded from this analysis because they represent a different trophic chain with little direct trophic connection to terrestrial ecosystems (Pimm et al. 1989).

A species was considered to be an exotic if either it was introduced to south Florida by humans, or if it was a non-indigenous species that invaded south Florida after the time of the European colonization. A species was considered to be

endangered if it was listed by the state of Florida as being extinct, endangered, threatened, or a species of special concern (Florida Game and Fresh Water Fish Commission 1994). A listed subspecies was included only if it was the sole subspecies present in the Everglades Ecoregion.

In most cases, vertebrate body masses were collected from published accounts or unpublished field data. For a portion of the herpetofauna, no published records of body masses were available and body mass was determined by weighing a sample of preserved museum specimens. Although some weight changes occur during the preservation process, these changes tend to be less than 10% (Haighton 1956, Mount 1963). In all cases, adult male and female weights were averaged.

To test the body-mass difference hypothesis, the mean body mass of the endangered species was compared to the mean of the native, non-endangered species for each vertebrate group. Then the median body mass of the exotic species was compared to the median body mass of the native species for each group. Mann-Whitney U tests were used either because the data were not normally distributed, or because the variances were not equal. An alpha value of $< 0.1$ was considered biologically significant because the power of many of the tests was low (Lipsey 1990). I determined if endangered species tended to be the largest member of their families by determining family membership of all species, the number of endangered species within each family, and whether the largest member of the family was listed as endangered.

The diet differences and species replacement hypotheses both concerned niche use. Because the sample size for the endangered and exotic species was small, niche definitions and categories were broad; this allowed conservative comparisons to be

made. Niche classification for the mammals was determined by diet and strata, using a modified classification scheme from Eisenberg (1981; Appendix A). Diet was divided into three categories: carnivore, omnivore, and herbivore (including granivores and frugivores). Foraging strata also were divided into three general groups: semi-aquatic, terrestrial, and volant. Niche classification for the herpetofauna used the same diet classification, but divided the strata into the categories fossorial, terrestrial, and arboreal. For the birds, niche classification was based on the methods of Ehrlich et al. (1988), but also was collapsed into fewer groups. Diet was classified using the same scheme as for the mammals and the herpetofauna. Foraging strategy was separated into four groups: ground foragers, foliage foragers, arboreal (soaring) foragers, and aquatic (non-soaring) foragers.

To test if the diet of exotic species differed from that of the endangered species, the number of carnivores, omnivores, and herbivores in the endangered group was compared to the numbers in the exotic group. Because of the small sample sizes involved, the number of omnivores and herbivores was combined and compared to the number of carnivores in each taxonomic group. A Fisher's exact test was used if more than 20% of the cells in the comparison were <5; otherwise a chi-square goodness-of-fit test was used.

The replacement hypothesis was tested by classifying each endangered and invasive species by a diet and foraging/habitat niche, and then comparing niches between each invasive species and the endangered species closest in size, within each vertebrate group. The proportion of exotic species that replaced endangered species

was compared among all three taxonomic groups using a chi-square goodness-of-fit test to determine if replacement was occurring.

The phylogeny hypothesis was tested after first determining family membership of all south Florida vertebrates. Then I determined the overall number of species within each family and the number of species within each family listed as extinct, endangered, declining, or a species of special concern. This allowed for the calculation of the random probability of a listed species being the largest in a given family. Using only those families where the probability of a listed species being the largest was greater than 0 and less than 1, the Breslow-Day Test for homogeneity of odds ratios (SAS Inst. 1994) was used to determine whether, within a taxa, family data could be pooled. If so, the Cochran-Mantel-Haenszel Statistic (SAS Inst. 1994) was used to test if the largest member of a family tended to be listed. This test allowed larger families to have more weight in the calculations.

## Results

At least one third of all vertebrate species in south Florida are either endangered or exotic (Appendix A; Table 1-1). No statistical difference in body mass between endangered and persistent native species was found except in the birds, although the trends in all groups suggest that endangered species may have a higher body mass than persistent native species (Table 1-2).

Exotic species were not found to be significantly smaller than native (endangered and non-endangered) species in any of the taxonomic groups. The diet difference hypothesis was only supported for avifauna. The diet of the exotic avifauna

is different from the endangered avifauna (Table 1-3). The majority of the exotic birds are herbivores, while most endangered birds were carnivores. The results of the mammal and herpetofauna comparisons showed no support for the diet difference hypothesis. Nearly all of the native and exotic herpetofauna was classified as carnivorous; few species were omnivorous or herbivorous.

Table 1-1. Number, proportion, and mean body mass of the population classes of the vertebrates of the south Florida ecosystem.

| Taxa | Class | N | % of Total | Body Mass(g) | SE |
|---|---|---|---|---|---|
| AVIFAUNA | non-endangered | 85 | 59% | 392.0 | 82.6 |
| | endangered | 21 | 15% | 896.6 | 318.3 |
| | non-indigenous | 37 | 26% | 480.5 | 153.8 |
| HERPETOFAUNA | non-endangered | 42 | 59% | 65.6 | 22.2 |
| | endangered | 8 | 11% | 415.8 | 321.1 |
| | non-indigenous | 21 | 30% | 291.5 | 220.6 |
| MAMMALS | non-endangered | 26 | 57% | 5215.6 | 3342 |
| | endangered | 9 | 20% | 26884.7 | 17152 |
| | non-indigenous | 11 | 24% | 15047.9 | 10142 |

The species replacement hypothesis was not supported. The majority of the exotic species did not fill the niches of the endangered species. Significantly more of the exotic species occupied different niches than occupied the same niche as the endangered species ($\underline{X} = 5.97$, $\underline{df} = 2$, $\underline{P} = 0.045$). Thirty exotic birds, 17 reptiles and amphibians, and six of the exotic mammals differed in niche from the species closest to them in body mass. Only four exotic birds, four exotic herpetofauna, and five exotic mammals directly replaced similar-sized animals in niche.

Table 1-2. Comparisons among the body mass distributions of the vertebrates of the south Florida ecosystem. Mann-Whitney U statistic (T) and probability (P) are given for comparisons between the body mass of non-endangered native species and the endangered species, and the native species inclusive of endangered status and non-indigenous species.

| Taxa | Class | Median Body Mass(g) | T | P |
|---|---|---|---|---|
| AVIFAUNA | non-endangered | 119 | | |
| | endangered | 371 | 1361.5 | 0.06 |
| | natives | 140 | | |
| | non-indigenous | 149 | 2765 | 0.64 |
| HERPETOFAUNA | non-endangered | 11 | | |
| | endangered | 48 | 241 | 0.27 |
| | natives | 11 | | |
| | non-indigenous | 9 | 737.5 | 0.92 |
| MAMMALS | non-endangered | 180 | | |
| | endangered | 925 | 192 | 0.27 |
| | natives | 243 | | |
| | non-indigenous | 3900 | 330.5 | 0.07 |

There was no clear relationship between endangerment and body size position within a family (Table 1-4). Seventeen families composed of at least two species included an endangered species. In all cases, families could be pooled within a taxa. Only for the herpetofauna, which provided usable data for only four families, was the phylogenetic hypothesis weakly supported ($P = 0.041$). There was no relationship between the largest member of a family and listed status for birds ($P = 0.63$) or for mammals ($P = 0.12$).

Table 1-3. Diet comparisons among the south Florida vertebrate fauna. Chi-square and Fisher's Exact tests compared the carnivores to the herbivores and omnivores combined. Yates correction of continuity was used in the Chi-square test. Fisher's Exact Test is an exact probability test, without degrees of freedom.

| Taxonomic group | Class | Carn. | Omn. | Herb. | $X^2$ | df | P |
|---|---|---|---|---|---|---|---|
| AVIFAUNA | End. | 16 | 2 | 3 | | | |
| | Exotic | 6 | 1 | 30 | 18.0 | 1 | 0.001 |
| HERPETOFAUNA | | | | | | | |
| | End. | 7 | 0 | 1 | | | |
| | Exotic | 17 | 4 | 0 | -- | -- | 1.000 |
| MAMMALS | End. | 4 | 2 | 3 | | | |
| | Exotic | 3 | 4 | 4 | -- | -- | 0.642 |

## Discussion

It is likely that there will be many changes in the future vertebrate fauna of south Florida, but few of the potential changes in the fauna are predictable using commonly invoked body mass and diet based hypotheses. Extinct and declining species will not be replaced by ecologically similar species, nor will they be replaced only by small herbivores and omnivores.

Some of the results may be explained by habitat affinity. Species that inhabit only a few habitats in a limited range (i.e., endemics) are likely to become endangered

Table 1-4. Vertebrate families in the south Florida ecosystem, with number of species represented in the family (N), the number of species that are listed as endangered within a family (Ne), whether or not the largest (large) family member was endangered (yes or no), and the probability of the largest species within a family being endangered (P random).

| Taxa | Family | N | Ne | Large | P random |
|---|---|---|---|---|---|
| AVIFAUNA | Accipitridae | 7 | 2 | Yes | 0.29 |
| | Alcedinidae | 1 | 0 | - | - |
| | Anatidae | 3 | 0 | - | - |
| | Apodidae | 1 | 0 | - | - |
| | Aramidae | 1 | 1 | Yes | 1.00 |
| | Ardeidae | 11 | 4 | No | 0.36 |
| | Caprimulgidae | 2 | 0 | - | - |
| | Cathartidae | 2 | 0 | - | - |
| | Charadriidae | 1 | 0 | - | - |
| | Ciconiidae | 1 | 1 | Yes | 1.00 |
| | Columbidae | 3 | 1 | Yes | 0.33 |
| | Corvidae | 4 | 1 | No | 0.20 |
| | Cuculidae | 2 | 0 | - | - |
| | Falconidae | 2 | 2 | Yes | 1.00 |
| | Gruidae | 1 | 1 | Yes | 1.00 |
| | Hirundinidae | 1 | 1 | Yes | 1.00 |
| | Icteridae | 4 | 0 | - | - |
| | Laniidae | 1 | 1 | Yes | 1.00 |
| | Meleagrididae | 1 | 0 | - | - |
| | Mimidae | 2 | 0 | - | - |
| | Pandionidae | 1 | 0 | - | - |
| | Paridae | 1 | 0 | - | - |
| | Parulidae | 7 | 0 | - | - |
| | Phalacrocoracidae | 1 | 0 | - | - |
| | Phasianidae | 1 | 0 | - | - |
| | Picidae | 8 | 2 | No | 0.25 |
| | Ploceidae | 5 | 3 | No | 0.60 |
| | Podicipedidae | 1 | 0 | - | - |
| | Psittacidae | 1 | 1 | Yes | 1.00 |
| | Rallidae | 5 | 0 | - | - |
| | Recurvirostridae | 1 | 0 | - | - |
| | Scolopacidae | 2 | 0 | - | - |
| | Sittidae | 1 | 0 | - | - |
| | Strigidae | 4 | 0 | - | - |
| | Sylviidae | 1 | 0 | - | - |
| | Thraupidae | 1 | 0 | - | - |

Table 1-4 cont.

| Taxa | Family | N | Ne | Large | P random |
|---|---|---|---|---|---|
| | Threskiornithidae | 3 | 1 | Yes | 0.33 |
| | Trochilidae | 1 | 0 | - | - |
| | Troglodytidae | 1 | 0 | - | - |
| | Turdidae | 1 | 0 | - | - |
| | Tyrannidae | 3 | 0 | - | - |
| | Tytonidae | 1 | 0 | - | - |
| | Vireonidae | 3 | 0 | - | - |
| HERPETOFAUNA | | | | | |
| | Anguidae | 3 | 1 | No | 0.33 |
| | Bufonidae | 2 | 0 | - | - |
| | Colubridae | 18 | 3 | Yes | 0.17 |
| | Elapidae | 1 | 0 | - | - |
| | Emydidae | 1 | 0 | - | - |
| | Hylidae | 8 | 0 | - | - |
| | Iguanidae | 3 | 1 | Yes | 0.33 |
| | Microhylidae | 1 | 0 | - | - |
| | Pelobatidae | 1 | 0 | - | - |
| | Plethodontidae | 1 | 0 | - | - |
| | Ranidae | 3 | 1 | Yes | 0.33 |
| | Scincidae | 3 | 0 | - | - |
| | Teiidae | 1 | 0 | - | - |
| | Testudinidae | 1 | 1 | Yes | 1.00 |
| | Viperidae | 3 | 0 | - | - |
| MAMMALS | Canidae | 3 | 1 | Yes | 0.33 |
| | Cervidae | 1 | 0 | - | - |
| | Cricetidae | 7 | 1 | No | 0.14 |
| | Didelphidae | 1 | 0 | - | - |
| | Felidae | 2 | 1 | Yes | 0.50 |
| | Leporidae | 2 | 0 | - | - |
| | Molossidae | 2 | 1 | Yes | 0.50 |
| | Muridae | 1 | 1 | Yes | 1.00 |
| | Mustelidae | 5 | 1 | No | 0.20 |
| | Procyonidae | 1 | 0 | - | - |
| | Sciuridae | 3 | 1 | Yes | 0.33 |
| | Soricidae | 1 | 1 | Yes | 1.00 |
| | Talpidae | 1 | 0 | - | - |
| | Ursidae | 1 | 1 | Yes | 1.00 |
| | Vespertilionidae | 4 | 0 | - | - |

if their habitat is destroyed (e.g., White-crowned pigeons, Florida Keys mole skink, Florida mouse). Exotic species that succeed may be those that do best in disturbed, urban, or agricultural environments (e.g., Rock Dove, Mediterranean gecko, Black rat). In addition, chance may play a large role in which exotics are present in south Florida. Most of the successful exotics belong to a larger source pool of species that have been brought to the United States by man.

Despite the decline of native species, species richness will increase as exotics continue to colonize south Florida. The new "hotspots" of vertebrate biodiversity in Florida might be found in agricultural, suburban, and urban areas that support the most exotics. Habitat destruction and fragmentation in south Florida may be increasing local biodiversity, and masking the declines in native species richness (Samson and Knopf 1982).

In general, commonly invoked hypotheses explaining species' deletions and invasions, largely based on body size and niche, were not supported. The literature is full of generalizations concerning which species are likely to become endangered, and which are likely to invade, but these generalizations are based on extremely limited samples or "case studies," or congeneric comparisons. Currently, more is unknown concerning the process of species deletions and invasions than is known. The processes responsible for species invasions and deletions may be related more to community structure than inherent characteristics of the species involved. Community and ecosystem-level investigations are most likely to increase our knowledge of biological invasions and deletions.

# CHAPTER 2
# LUMPY PATTERNS OF BODY MASS PREDICT INVASIONS AND EXTINCTIONS IN TRANSFORMING LANDSCAPES

## Introduction

Conservation of biological diversity requires understanding why some species become extinct while other species are successful invaders. I focused on a quantitative analysis of four suggested traits in the previous chapter, but several other hypotheses also have been suggested. Many hypotheses explaining species success or failure focus on intrinsic species characteristics such as body size, niche, behavior, and geographic range. Small body size, broad diet, broad niche, high fecundity, longevity, high mobility and large native range have been proposed as characteristics of successful invasive species (di Castri 1990, Lodge 1993a, Lodge 1993b). Similarly, large body size, longevity, low fecundity, high trophic level, high dietary specialization, low natural abundance and a small geographic range have been associated with rare, declining or extinct species (Pimm et al. 1989, Terborgh 1974). While some extinction-prone or invasive species possess some of these characteristics, none are able to make consistent predictions across taxa and ecosystems. Other studies have linked anthropogenic or natural disturbances to changes in community membership (Diamond and Veitch 1981, Elton 1958). Approaches based on modeling (e.g., Pimm

1991) have provided interesting generalizations but remain non-predictive, and fail to integrate species and species-communities with landscapes and ecosystems.

The failure of these hypotheses may be due to an overly narrow characterization of ecological communities. Here I explore broad patterns that emerge from the relationships among ecological processes, landscape structure and communities of animals in order to gain predictive insight on species invasions and extinctions.

Landscape pattern is scale dependent (Milne et al. 1992) and different sized animals living upon the same landscape perceive their environment at different scales (Holling 1992, Milne et al. 1989). Increasing evidence suggests that ecosystems are structured by relatively few key processes operating at specific temporal and spatial scales (Carpenter and Leavitt 1991, Holling 1992, Levin 1992). The distinct temporal frequencies and spatial scale characterizing these key processes creates hierarchical landscape structures with scale specific pattern. The scale-specific effect of key processes leads to a discontinuous distribution of ecological structure and pattern (Burrough 1981) which in turn entrains attributes of animals residing on the landscape (Holling 1992). This entrainment reflects adaptations to a discontinuous pattern of resource distribution acting on animal community assembly and evolution both by sorting species and by providing a specific set of evolutionary opportunities and constraints. On the animal community level, this is expressed by a *lump-and-gap architecture* (or lump structure) of species body masses (Holling 1992). Body mass distributions are discontinuous, with distinct lumps of masses separated by distinct and detectable gaps. The lump structure in animal communities is similar across taxa within

landscapes and between landscapes with similar structure (Holling et al. 1996, Restrepo et al. 1997). Animals within a particular body-mass lump perceive and exploit the environment at the same range of scale. Animals in different lumps interact with their environment at different scales. Processes such as community assembly, biological invasions, and extinctions may be better understood by investigating interactions and phenomena within and across distinct ranges of scale.

The key processes that organize ecological systems are robust to most internal and external disturbances (Holling et al. 1996). However, when disturbance exceeds the resilience of a system, the system may reorganize around a new set of processes (Estes and Duggins 1995, Holling 1973, O'Neill et al. 1989, Walker et al. 1969). This in turn causes a change in landscape structure and entrained animal communities. Thus, invasions and extinctions are an expected result and an early indicator of any disturbance exceeding the resilience of a system. Understanding the relationship between community structure, perturbation (disturbance affecting processes), and biological invasions and extinctions may provide a theoretical basis for predicting invasions and extinctions and for assessing the vulnerability of different systems to these phenomena.

The lump and gap architecture of animal communities is the result of the interaction between key self-organizing processes, landscapes, and animals. Human development of landscapes changes some of the self-organizing processes so that landscape patterns begin to be transformed. I propose that this transformation should first affect the areas of transition between distinct ranges of scale, so that the first species affected are likely to be at the edge of body mass lumps. I tested this and

competing hypotheses by determining if invasive species and extinct or declining species are non-randomly distributed in terms of vertebrate community lump-and-gap architecture.

## Methods and analysis

### Species lists

I used data from the Everglades ecoregion of south Florida to investigate the relationship between lump-and-gap architecture of animal communities and biological invasions and extinctions. This region has experienced large scale transformations, and a large number of biological invasions. In addition, a large percentage of the terrestrial vertebrate fauna is listed as threatened or declining, or is extinct. Three general vertebrate taxonomic groups were used as replicates: reptiles and amphibians ("herpetofauna"), birds, and mammals. Species distributions were determined from museum records, published accounts, and the Florida Breeding Bird Atlas (Kale et al. *In Press*). Only species that had established breeding populations in the Everglades ecoregion (Bailey 1983) were included in the analysis. Because species distributions were available at the county-level, I used records from the Everglades Ecoregion counties of Dade, Monroe, Broward, Collier, Palm Beach, Hendry, and Lee. Pelagic and primarily aquatic species were excluded from the analysis because they interact with their environment differently than terrestrial species (Holling 1992) and may be trophically compartmentalized from terrestrial systems (Pimm and Lawton 1980).

A species was considered to be a biological invader if it became established after it was introduced to south Florida by humans ("introduced" or "exotic") or if it

was a nonindiginous species that naturally expanded its range ("invasive") following anthropogenic landscape transformations associated with European colonization. A species was considered to be endangered if it was listed by the state of Florida (Florida Game and Fresh Water Fish Commission 1994) as being extinct, endangered, threatened, a species of special concern, or in need of further study with suspected declines (hereafter, declining species). Listed subspecies were not included unless they were the only subspecies occurring in south Florida, or if all subspecies were listed.

In most cases, data on vertebrate body masses were collected from published sources. For a portion of the herpetofauna, body mass was determined from unpublished field data or by weighing a sample (n=10) of preserved museum specimens. Although some weight changes occur during the preservation process, these changes tend to be less than 10% (Haighton 1956, Mount 1963). In all cases, adult male and female weights were averaged.

Analysis

The goals of my analysis were outwardly simple. First, I sought to determine if the three taxonomic groups analyzed were distributed discontinuously, and if so, I sought to determine where discontinuities occurred in the data (i.e., determine the lump-and-gap architecture of the pre-invasion faunas). Second, I sought to determine whether invasive, and extinct and declining species were randomly or non-randomly distributed in relation to the lump-and-gap architecture.

All native species within each vertebrate class (including recently extinct species) were ranked in order of body mass to determine if discontinuities existed within the ranked distribution of the recent historical fauna (Figure 2-1). Invasive

species were not included in the faunal list when determining present lump-and-gap architecture. Body masses were analyzed using a null model and computer simulations that compared actual data with a unimodal continuous null distribution. The results were confirmed using a form of the split moving-window boundary analysis (SMW) (Webster 1978, Ludwig and Cornelius 1987), a sensitive method used to locate discontinuities that may exist within serial data. Because SMW is a subjective method (Corneilius and Reynolds 1991) these lumps were further verified using cluster analysis (PROC CLUSTER, SAS inc. 1985). Because sample size in my three data sets varied from 35 (mammals) to 106 (birds), and because I was most interested in determining community structure, I maintained a constant statistical power of approximately 0.50 when detecting discontinuities. Due to this power adjustment, alpha varied from 0.07 to 0.20 among the three data sets.

A gap was defined as an area between successive body masses that significantly exceeded the expectations generated by a continuous null distribution. Thus a species lump was a grouping of body masses not exceeding the expectation of the null distribution. Lumps were defined by the two endpoint species that defined either the upper or the lower extremes of the lump. A species was considered within a lump if it was not a species defining the edge of a lump; those species defining a lump edge were considered lump/gap edge species (Figure 2-1).

Invasive and declining species could be distributed in the lump-and-gap architecture of the animal communities in at least five possible patterns (Figure 2-2). The first possibility is that they were randomly distributed, which would indicate that scale specific structure was not related to invasions or declines. The second is that

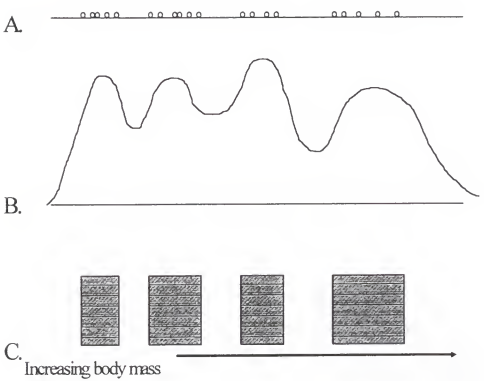


Figure 2-1. The rank-ordered distribution of animal body masses are discontinuous. A). Location of species in a hypothetical community along a log transformed body mass axis. Species form distinct groupings, separated by gaps. B). Density plot of data from A. C). Stylized portrayal of the lump-and-gap architecture of the hypothetical animal community in A.

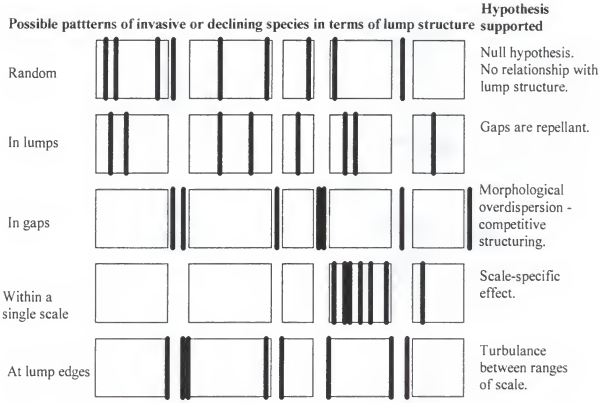
Possible pattterns of invasive or declining species in terms of lump structure
Hypothesis supported
Random
Null hypothesis. No relationship with lump structure.
In lumps
Gaps are repellant.
In gaps
Morphological overdispersion - competitive structuring.
Within a single scale
Scale-specific effect.
At lump edges
Turbulance between ranges of scale.

Figure 2-2. Possible pattern of invasions or deletions in the context of lump-and-gap architecture. Different pattern, or a lack of pattern support different hypotheses.

invasive species could be distributed within lumps well separated from the gaps, which would indicate that gaps are "forbidden zones," but tell us little else. The third possibility is that invasive and declining species could be restricted to 1 or a limited number of lumps, which would indicate that it is at the scale represented by these groupings of species that perturbation has had its greatest impact (e.g., Morton 1990). Fourth, invasive species could occur only in gaps, which we would interpret as indicative of competitive processes unrelated to scale specific animal community structure (morphological overdispersion; Moulton and Pimm 1986). The fifth possibility is that invasive and declining species occur at the edge of lumps, which would indicate that the areas between distinct ranges of scale are most susceptible to changes in ecological process and landscape structure.

After determining the lump and gap architecture of the historical faunas, I visually inspected the distributions for the patterns described above. Adding invasive species to the extant community structure may be likened to throwing darts at the distribution, and determining if there was pattern to where the darts stuck. For endangered species I quantified the pattern of listed species within the overall community. Chi-square analysis was used to compare observed with expected frequencies, with taxonomic groups used as replicates.

## Results

The south Florida herpetofauna, bird, and mammal body mass distributions were discontinuous. Distinct lumps of species were detected in each taxa, by all

methods. Herpetofauna, mammals and birds had 7, 6 and 13 distinct lumps, respectively.

Invasive and declining species were non-randomly distributed in relation to the lump-and-gap architecture of the faunas. Both invasive and declining/endangered species were concentrated at the edge of lumps in the lump-gap-architecture of each taxonomic group. For both invasive ($X^2$ = 12.94, 2 df; P = 0.002) and declining ($X^2$ = 8.61, 2 df; P = 0.01) species, across all taxonomic replicates, approximately twice as many species as expected are lump edge species (Table 2-1; Figures 2-3, 2-4, 2-5). No other patterns in the data were detected.

Table 2-1. Occurrence of endangered and declining, and invasive species at body mass lump edges in the Everglades Ecosystem vertebrate fauna. A large percentage (obs) of both declining and invasive species occur at body mass lump edges. Expected (percent) declining and invasive fauna occurring at lump edges are given in brackets.

| | NATIVE | LISTED | | | INVASIVE | | |
|---|---|---|---|---|---|---|---|
| | *n* | *n* | at edges(%) | | *n* | at edges(%) | |
| | | | obs | (exp) | | obs | (exp) |
| Herpetofauna | 50 | 7 | 57 | (28) | 21 | 29 | (16) |
| Avifauna | 106 | 21 | 38 | (24) | 36 | 25 | (13) |
| Mammals | 35 | 9 | 78 | (34) | 11 | 55 | (19) |
| Avg. % at scale breaks (exp) | | | 58 | (29) | | 36 | (16) |

As an independent test of endangered species association with lump edges, I also analyzed the cave bats of Mexico. The main cave roosting bats of Mexico comprise 28 species, nine of which have been categorized as fragile or vulnerable (Arita-Watanabe 1992). Eight of the nine species categorized as fragile or vulnerable

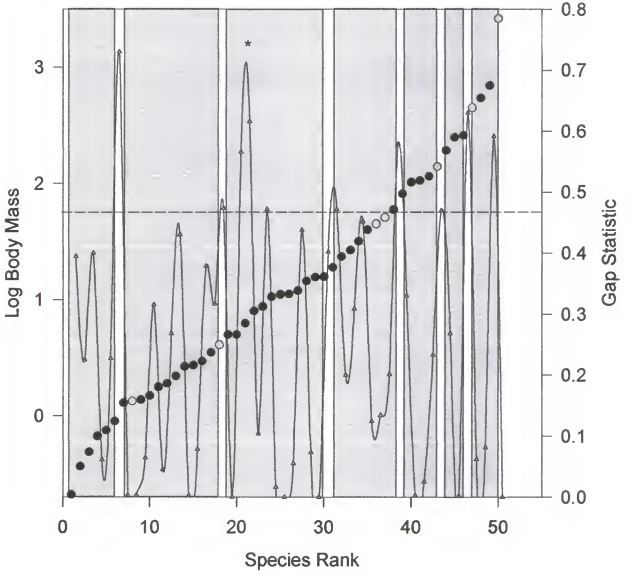


Figure 2-3. Body mass distribution (circles), lump structure (shaded rectangles), gap statistic, and occurrence of listed species (open circles) for Everglades herpetofauna. Power for detecting gaps was kept constant.

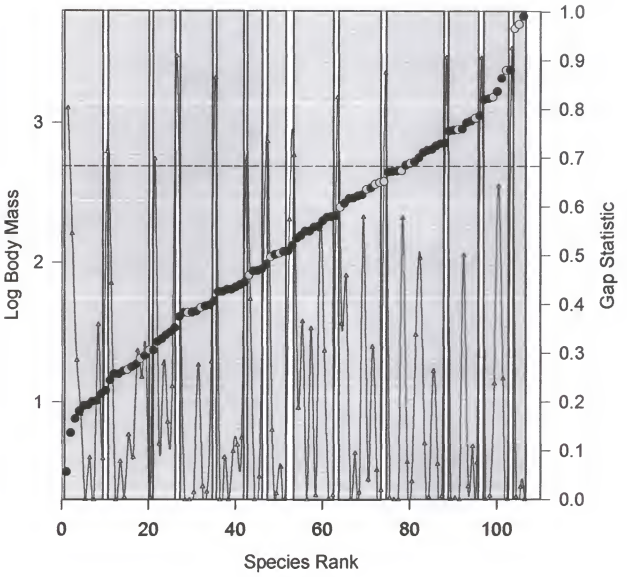


Figure 2-4. Body mass distribution (circles), lump structure (shaded rectangles), gap statistic, and occurrence of listed species (open circles) for Everglades birds. Power for detecting gaps was kept constant.

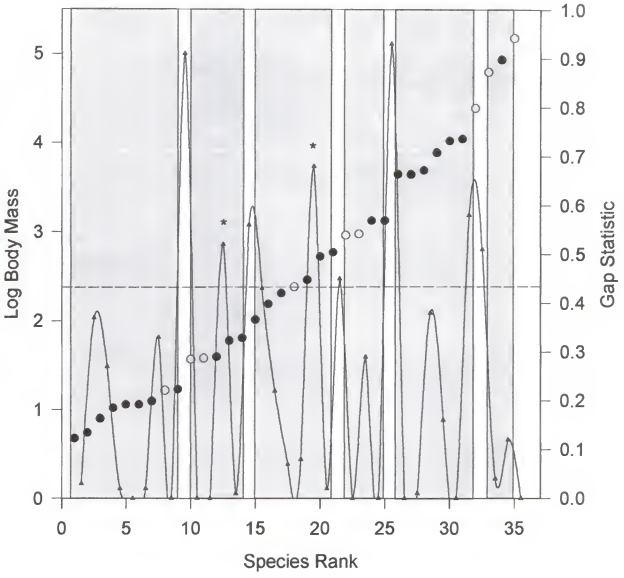


Figure 2-5. Body mass distribution (circles), lump structure (shaded rectangles), gap statistic, and occurrence of listed species (open circles) for Everglades mammals. Power for detecting gaps was kept constant.

had body masses located at the edge of body mass lumps (Figure 2-6). If that distribution were random, I would have expected fewer than four fragile or vulnerable species to occur at lump edges. Chapter 5 provides additional tests of this hypothesis using the bird and mammal communities of mediterranean-climate ecosystems in Australia, Chile, the Mediterranean Basin, South Africa, and the United States.

## Discussion

The strong correspondence between two independent attributes (population status and body-mass lump structure) in three different taxa further confirms the idea that lumpy body mass distributions are real (Holling 1992). It may seem surprising that both invasive and declining species are located at the edge of body-mass lumps. These results suggest that something similar must be shared by the two extreme biological conditions represented by invasive species and declining species.

Diamond and Veitch (1981) hypothesized that species invasions and deletions were related to one another and dependent on disturbance. They hypothesized that disturbance led to the decline of certain native bird species, and that these deletions therefore enabled invading species of birds to succeed. I do not agree that such a cause and effect chain of disturbance-extinction-invasion (Diamond and Veitch 1981) is the primary reason for the association. Rather, I hypothesize that perturbation of processes leads to changes in ecosystem structure, which in turn yields predictable scale-dependent changes in vertebrate community structure. That is, invasive and endangered species respond to changes of resources at the same scale and not necessarily to the shift in competitive balance between them.

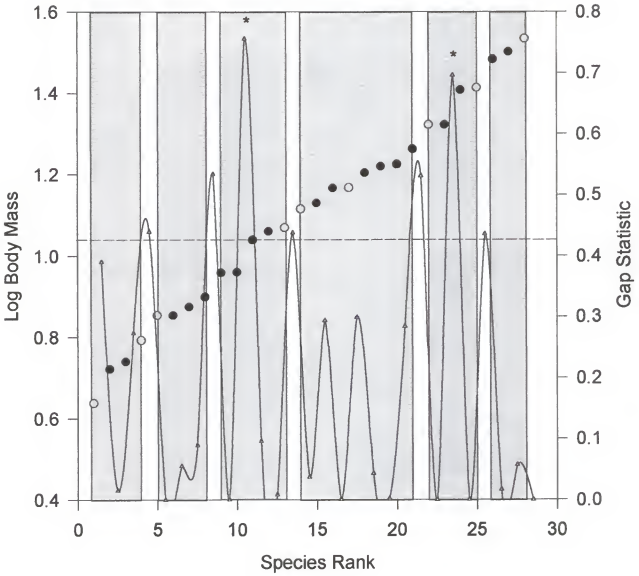


Figure 2-6. Body mass distribution (circles), lump structure (shaded rectangles), gap statistic, and occurrence of listed species (open circles) for Mexican cave bats. Power for detecting gaps was kept constant.

Note that my investigation has used definitions of endangerment and decline derived by an administrative process of government. Such definitions are conservative and tend to lag behind actual fluctuations in animal populations. For invasive species, historical contingency has played a large role in introductions. For instance, small animals such as mice and rats often are inadvertently transported, but antelope have likely never been stowaways on a ship or plane. I do not think it is useful to describe historical happenstance such as the obvious fact that smaller species are more easily transported. The relevant questions are, given that a number of species are introduced, which will succeed, and why. I believe that the scale of environmental use by a species and landscape-level ecological transformation are most important in predicting species success or failure. For example, both the Smooth-billed Ani (*Crotophaga ani*) and the Scrub Jay (*Aphelocoma coerulescens*) are of similar body mass, located at the edge of body-mass lumps, and perceive the environment at the same range of scale. The former has invaded Florida since the 1930s while the latter continues to decline. These species probably do not compete for food, however, but share a similar scale of environmental perception and response. Landscape changes that favor the Ani, i.e., increased brushy growth, tend to create unfavorable conditions at the same scale for the Scrub Jay. In both cases the proximate and ultimate cause of invasion/decline is landscape level change in ecological pattern caused by anthropogenic alteration of structuring processes.

I hypothesize that the expected results of disturbance that exceeds the resilience of an ecological system are simultaneous events of invasion and deletion (Figure 2-7). Key processes structure ecosystems in a self-organizing fashion. Large

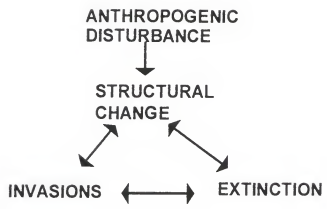


Figure 2-7. The relationship between disturbance, ecological structure, invasions, and extinctions. Disturbance exceeding the resilience of a system affects ecological structure, which in turn leads to changes in animal communities. Additionally, changes in animal community membership may in turn lead to further changes: invasions, especially by predators, may lead to further declines in native species (Simberloff 1981), and extinctions may lead to further invasions (Diamond and Veitch 1981).

scale anthropogenic disturbance and land-use change may exceed the resilience of a system, disrupting the key processes that structure ecosystems and entrain biotic variables. When the resilience of a system is exceeded, new processes begin to control the system, and landscape structure proceeds through a transition to a new dynamic stable state. This change in key processes causes a temporary loss of ecological integrity as landscape structures reorganize and results in changes in the lump-and-gap architecture inherent in animal communities. Because animal communities in an ecosystem are entrained by ecological structure, perturbation affects the structure of animal communities. Changes in key processes cause a transition from one type of

self-organizing landscape structure to another. This results in changes in the animal community, including successful animal invasions and the decline or extinction of susceptible native species. Non-native species whose body masses place them at the edge of body mass lumps are able to successfully establish breeding populations. Simultaneously, conditions become unfavorable for some other species that cannot adapt to the new conditions found by animals near gaps in the community structure. Species with body masses near lump edges are the first to encounter changes occurring as landscape patterns start to transform. Species within lumps are adapted to a set of patterns least sensitive to change.

At a global scale, rapid anthropogenic disturbance is affecting the processes that structure most ecosystems. Whether these disturbances will exceed the resilience of the systems will depend on a variety of mostly unknown factors. Faster, smaller variables (such as individual species) may influence the larger slower variables in an ecosystem (e.g., Ludwig et al. 1978, Prins and Jeud 1993). Feedback from variables adapted to the altered ecosystem structure (e.g., invasive species) helps prevent return to the original state. As more invasive species become established, they may further alter the environment and promote or entrench structural change. In south Florida, continuing invasions and declines in native species indicate that the community is still in a state of flux, reacting to changes in landscape structures that lag behind changes in disturbance regimes. Even if original key processes are re-established, the original animal community is not likely to be re-assembled (Case 1990, Drake et al. 1996). The impossibility of re-assembling the original animal communities casts doubts on our

ability to restore greatly disturbed communities to their original state even after anthropogenic disturbances are removed.

There are unusual characteristics associated with the edge of body-mass lumps, because these are areas of biological turbulence. The edges of lumps may be considered zones of crisis and opportunity depending on the way a given species at these scales exploits resources and interacts with its environment, and may be analogous to zones of phase transition. In perturbed systems, biological invasions and deletions tend to occur at lump edges. The correlation I have demonstrated between invasiveness/decline and the edge of body-mass lumps is likely to hold in transforming landscapes. In more stable or restored landscapes, I hypothesize that the correlation will disappear as other threats become dominant. In changing landscapes, phase transitions between distinct ranges of scale are zones offering both opportunity and crisis. Chaotic and highly variable behavior such as this has been demonstrated for the area between domains of scale in physical systems (Nittmann et al. 1985, O'Neil et al. 1986, Grebogi et al. 1987), and postulated for biological communities (Weins 1989). This investigation is the first to document unusual characteristics associated with scale breaks in animal communities.

# CHAPTER 3
# UNSUCCESSFUL NON-INDIGENOUS AVIFAUNA IN SOUTH FLORIDA

## Introduction

The investigation of biological invasions has historically focused on the traits of individual species. It has been rarely, if ever, possible to take a broad and systematic view, because of extreme limitations in available data. In general, investigations at the species-level have failed to produce any paradigms useful for the prediction of invasion success. Inherent traits of species, such as body mass and reproductive capacity, may influence the success of invaders but may describe historical contingency more than offer predictive insight. Possessing certain traits does not necessarily lead to introduction success. Compiling a list of traits associated with invasive species is simple, but the list is likely to be long and vary greatly with the compilers background and experience. A few traits often are associated with invasion success, notably high *r*, small body size, and high mobility. However, most traits suggested as correlates of invasion success are actually associated with very few successful non-indigenous species. No individual-level traits predict invasion success; those that may be highly correlated with invasiveness remain general, vague, and have little predictive value.

More recently, community-level investigations have taken a broader look at biological invasions in the context of interactions among community members (e.g., Moulton and Pimm 1983, Lockwood and Moulton 1994), especially in the context of

model communities (e. g., Pimm 1991). Community-level investigations have increased our understanding of invasions, suggesting that competitive interactions among species influence invasion success and that resistance to invasions is a community level phenomena (Case 1990, Drake 1990a, Drake 1990b, Case 1996; but see Morton et al. 1996) that increases as communities approach saturation. Community-level interactions and characteristics of potentially invaded communities offer greater explanatory value for invasion success, and shed much more light onto the problem of predicting biological invasions, than single species studies. Community level factors such as strength of relationships between and among species (e.g., Pimm 1991), saturation level (Drake 1990a, Drake 1990b), and the presence of potentially strong competitors (Grant 1968) influence the success of potentially invasive or introduced species.

An understanding of biological invasions may be enhanced by examining landscape-level patterns, because community membership is ultimately determined not only by species traits and interactions, but also by elements of the landscape that provide suitable habitat templates, available resources, exploitable resource distributions in space and time, as well as barriers to dispersal. Decoupling the factors associated with a species' ability to invade, the invasibility of species communities, and interactions between the above and landscapes is difficult. Indeed, while most biologists study community-level interactions in the context of biological invasions by ignoring the landscape template, it is probably not truly possible to separate animals from the environment with which they interact, but unwise to do so as well.

Species do not operate in a vacuum, but rather interact with other community members to varying degrees. These interactions may be strongest among genera and families, but also may transcend taxonomic constraints and occur on the basis of ecological function (Peterson et al. 1998). Community membership is influenced by landscape-level processes affecting the mosaic of habitats and available structure for faunas. The importance of habitat structure has been well acknowledged for avifauna (James and Warner 1982), but is usually ignored for other taxonomic groups. Anthropogenic influence on landscapes, especially those that affect structuring processes (e.g., fire, hydrologic regimes, nutrient cycling) ultimately affect environmental structure and community membership. Ultimately, anthropogenic perturbations may change community membership by causing simultaneous events of invasion and extinction.

Most studies of biological invasions fail to incorporate unsuccessfully introduced species. In most cases information on unsuccessful introductions is simply not available, although exceptions occur for some oceanic islands where acclimation societies kept records of their efforts (Moulton and Sanderson 1997). In the sense of true invasions, it is not possible to know the potential, but unsuccessful, invaders. It is unclear what the species pool for potential invaders would be, and from where it should be drawn. Investigations of introductions on oceanic islands offer somewhat firmer ground for the delineation of species pools, but even here there is controversy, and changing the species pool changes the outcome of investigations based on the extrapolation of a potential species pool.

The continental avifauna of the south Florida peninsula offers a unique opportunity for the study of non-indigenous species. The introduced fauna is well documented, including failed introductions. A large number of species (>100) have been introduced, and a large number of these have established breeding populations (Chapter 1). Successful non-indigenous species now constitute approximately 25% of the breeding bird fauna of south Florida. Most introductions have been reasonably well documented, and it is possible to remove the effect of propagule size by considering only those species which were introduced in sufficient numbers for there to have been the possibility of successful establishment.

Recent logistic regression analysis by Veltman et al. (1996) concentrated on variables intrinsic to species (i.e., migratory status, body mass, phylogeny, range size, natality, habitat use) or associated with introduction effort (i.e., number of releases, propagule size). Variables affecting introduction success are of interest for endangered species management where it may be desirable to translocate individuals to establish additional populations, but my interest in understanding introduction success was based on a desire to predict and prevent the spread of harmful non-indigenous species, and gain insight into community ecology. My interest focuses on the negative impact of inadvertently introduced or invasive species. I was interested determining the factors associated with the success of inadvertently or purposely released species, and only included variables based on predictive theory. These variables included intrinsic traits of species, community level interactions, and landscape-level factors.

I used a multiple logistic regression model to determine what independent variables were significant predictors of introduction success. I chose variables for

which there were theory-based suggestions of influence on success. An alternative approach would have been to gather all the possible data on the species involved, and analyze that data - a shotgun approach. However, such an approach is less likely to increase our understanding because it could reflect historical contingency rather than less obvious patterns. For example, such an analysis for mammal introductions may indicate that smaller species are more likely to be established as non-indigenous species. However, this reflects the ease of inadvertent transport of small mammals but tells us nothing about which species would be likely to succeed if introduced.

The variables included in my analysis were body mass, distribution in a body mass lump or gap, distance to body-mass lump edge (in terms of body mass), distance to nearest neighbor (in terms of body mass), year of introduction, and presence of congeners. The variable body mass tested the prediction that small bodied species are more likely to be successful invaders than larger species. Body mass correlates with a number of other variables such as *r* (Eisenberg 1981), and has been repeatedly been suggested as a trait of invasive species. The remaining variables were associated with community or landscape level interactions and are discussed below.

Community-level variables

Three independent variables tested theory associated with community-level predictors of invasion success: distance to nearest neighbor (in terms of body mass), year of introduction, and presence of congeners. Distance to nearest neighbor in body mass terms may be considered a general measure of morphological similarity. One possible predictor of introduction success may be the absence of morphologically similar species, or at least maximization of morphological dispersion. In many

principal component analyses investigating morphological overdispersion within communities of introduced species, the first principal component is strongly associated with the overall size of a species (Moulton and Pimm 1986). Morphological overdispersion has been documented in a large number of introduced bird avifaunas. The result of morphological overdispersion in successfully introduced species may be a reduction of competition among community members, whether or not competition was the cause of the observed dispersion.

The variable nearest neighbor was the distance in log10 converted body mass to the nearest species in terms of body mass. If species in a community were competing based on morphological similarity (see also gap or clump membership, below) and body mass is a strong predictor of morphological similarity, I would expect successfully introduced species to be those that were most morphologically distinct.

The variable year of introduction tested for a priority effect among introductions. An observed priority effect would indicate that earlier introductions, when the species community contained fewer species, had a higher probability of success than later introductions. A body of evidence from analysis of introduced bird communities on oceanic islands suggests that a priority effect exists, but Simberloff (Simberloff and Boeklen 1991, Simberloff 1992) recently suggested that these effects were artifactual, and an "all or none" pattern of success more accurately predicts introduction success. That suggestion has been refuted (Moulton and Sanderson 1997). The results of various computer models suggests that a priority effect is expected in unsaturated communities, with the probability of successful invasion

decreasing as a community becomes increasingly saturated. No analysis of priority effect in continental faunas has been conducted previously.

The presence of congeners variable was included in my analysis because various investigations have suggested that competition plays an important role in the probability of successful establishment for introduced species (see above). Congeners are likely to compete most strongly because they are more likely to have similar morphology and ecology. Members of disparate genera also may compete, but it is difficult to *a priori* determine the strength of interactions among community members. This variable tested whether the presence of congeners influenced introduction success.

Landscape-level variables

Landscape-level variables were position in a body mass lump or gap, and distance to body-mass lump edge (in terms of body mass). These variables were chosen because they relate directly to the findings of a non-random distribution of non-indigenous species (Chapter 2) in terms of the "lump-and-gap architecture" of vertebrate body masses within a given landscape (Holling 1992, Restrepo et al. 1997, Holling et al. 1996). The hypothesis relating landscape structure to the discontinuous distribution of vertebrate body masses suggests that the scale-specific structuring effect of key ecological processes leads to a discontinuous distribution of ecological structure and pattern (Burrough 1981). The scale specific ecological structure inherent within landscapes entrains attributes of animals residing on the landscape (Holling 1992). This entrainment reflects adaptations to a discontinuous pattern of resource distribution acting on animal community assembly and evolution both by

sorting species and by providing a specific set of evolutionary opportunities and constraints. Body mass distributions are discontinuous, with distinct lumps of masses separated by distinct and detectable gaps. Animals within a particular lump perceive and exploit the environment at the same range of scale. Animals in different lumps interact with their environment at different scales. Processes such as community assembly, biological invasions, and extinctions may be better understood by investigating interactions and phenomena within and across distinct ranges of scale. Indeed, one of the most commonly invoked predictors of invasion success, the link between invasion and disturbance, is meaningless because disturbance is implicitly considered to be scale invariant.

I documented a non-random distribution, in terms of the lump-and-gap architecture, of invasive species for 3 taxonomic replicates (herpetofauna, birds, and mammals) from the south Florida sub-ecoregion (Chapter 2) and in Mexican cave bats. I proposed that simultaneous events of invasion and extinction are the expected results of perturbations that affect key structuring processes in a system, or other changes affecting the pattern of ecological structure on a landscape.

The variable distribution in a body mass lump or gap considers whether a species body mass places it into a lump of species or into a gap, where no species of similar body mass are found. The variable distance to body-mass lump edge (in terms of body mass) relates to the findings reported in Chapter 2 that suggest that invasive species whose body mass places them at the edge of body mass lumps are most likely to be successful, at least in landscapes in transition.

## Methods

### Data

Data on the species introduced into the south Florida Everglades sub-ecosystem were compiled from published sources, primarily Stevenson and Anderson (1994) and Robertson and Wolfenden (1992). Additional information was gathered from researchers working with non-indigenous species in the region (A. Van Doren, personal communication), and from the Florida Biodiversity Project (C. R. Allen, unpublished data). Because what constitutes an unsuccessful invasive species can not be determined with any surety, I used data only for introductions, both purposeful and inadvertent. This led to the elimination of the following species, included in previous analyses (Chapters 1, 2): *Hirundo fulva, Passer domesticus, Molothrus bonariensis, Molothrus ater, Icterus pectoralis, Sturnus vulgaris, Crotophaga ani, Bubulcus ibis, Columba livia, Branta canadensis.* Ducks of the genus Dendrocygna were more problematic. These species (*D. autumnalis* and *D. bicolor*) were both introduced but also perhaps naturally invasive. They were kept in the analysis.

I eliminated species introduced with little or no possibility of establishment due to an insufficient propagule. Because propagule size was not directly available in all cases, I considered only those species that were present for >5 years (primarily CBC data) and that were known or suspected to have bred (Pranty et al. *in press*) in south Florida on >1 occasion.

Body mass was determined from published sources, primarily Dunning (1993; Appendix C). Year of introduction was determined primarily from Stevenson and

Anderson (1994). Lump structure was as determined in Chapter 2, and the interpretation of lump structure in this analysis was the same as in Chapter 2.

Analysis

Success or failure of an introduction was the dichotomous response variable in logistic regression analysis. Non-indigenous species were divided into six groups. Group one were established introduced species. The following analysis included only species in the next two groups - unsuccessful introductions with sufficient propogules and possible species with potentially sufficient propagules. Species introduced with no chance for success are listed in Appendix D. Differentiation among introduced species is very difficult, so two analyses were conducted, one using successful introductions and unsuccessful introductions for which I had a high degree of confidence of sufficient propagule size, and the other also incorporating species that potentially had sufficient propagules. The independent variables used in this analysis were listed and discussed above. Variables were scaled to fall between approximately 0 and 100 (Menard 1995). A logistic model was fit to the data, and then the model was refined to reduce colinearity and increase model fit. Variables with a high degree of colinearity and/or high probability values (i.e., independent variables clearly without predictive value) were removed in a series of iterations to produce the model with the best overall fit. Thus, a final model was produced that considered only those variables with a potentially significant influence on introduction success. Variables which were determined to be significant predictors of introduction success were further tested with simple statistics, specifically Mann-Whitney U comparisons of the medians for those variables between the successfully and unsuccessfully introduced groups. A second set

of models were built that were somewhat more liberal in their consideration of introduced species (i.e., included species with potentially sufficient propagules), but that produced results that were not qualitatively different than more conservative models.

## Results

Considering only successful and unsuccessful introductions with a clearly adequate propagule at the time of introduction (success status 11 in Appendix C), the overall model fit was relatively poor ($P = 0.10$) and only two autocorrelated variables approached significance. (Table 3-1). These variables were Gap ($P=0.19$) and proximity to body-mass lump edge ($P=0.16$). I refined the logistic model to produce the model with the best overall fit (SAS Inst. 1994). This model ($P = 0.037$) included the independent variables edge distance ($P=0.063$), year ($P = 0.241$) and mass ($P = 0.587$) as independent variables. I further tested for differences between the median edge distance and median date of introduction of successfully introduced species and unsuccessful species with the non-parametric Mann-Whitney U test. In both cases, using two different interpretations of adequate propagule size, means differed between successful and unsuccessful introduced species (Table 3-2). Both the logistic regression model and median tests demonstrate that species whose body mass placed them proximate to a body-mass lump edge, and possibly species introduced earlier (see Table 3-2) were more likely to become successfully established.

TABLE 3-1. Logistic regression output using community and ecosystem-level variables to predict the success or failure of avian introductions in south Florida.

| Variable | Wald Statistic | Coefficient | Standard Error | P-level |
|---|---|---|---|---|
| Intercept | 0.124 | 0.586 | 1.660 | 0.726 |
| Body mass | 0.153 | 0.257 | 0.657 | 0.698 |
| Lump vs gap | 1.805 | -1.440 | 1.072 | 0.187 |
| Neighbor distance | 0.0932 | -11.371 | 37.250 | 0.762 |
| Edge distance | 2.044 | -28.797 | 20.142 | 0.161 |
| Year of intro | 0.863 | 0.0348 | 0.0375 | 0.359 |
| Native congener | 0.000338 | 10.821 | 588.181 | 0.985 |
| NIS congener | 0.0198 | -0.121 | 0.860 | 0.889 |

TABLE 3-2. Medians and P-level for tests comparing edge distance and year of introduction, between successful and unsuccessfully introduced species in south Florida. A). using only unsuccessfully introduced species which were clearly introduced with an adequate propagule. B). using unsuccessfully introduced species as in A, but also incorporating species which probably were introduced with an adequate propagule.

| | Median edge distance | Median year BP |
|---|---|---|
| A). | | |
| successful | 0.0217 | 27.00 |
| unsuccessful | 0.0318 | 21.00 |
| P-Level | 0.017 | 0.066 |
| B). | | |
| Successful | 0.0217 | |
| unsuccessful | 0.0262 | |
| P-Level | 0.0945 | |

The second analysis may be considered more liberal in terms of classification of unsuccessfully introduced species (success status 11, 12 and 13 in Appendix C): it is included because of the obvious pitfalls associated with such a classification. The

results are similar to those discussed above, in Table 3-1, and may be found in Table 3-3.

TABLE 3-3. Logistic regression analysis of successful versus unsuccessful bird species, using a more liberal interpretation of species introduced but unsuccessful at establishment.

| Variable | Wald Statistic | Coefficient | Standard Error | P-level |
|---|---|---|---|---|
| Intercept | 0.0251 | -0.241 | 1.522 | 0.875 |
| Body mass | 0.807 | 0.539 | 0.6000 | 0.374 |
| Lump vs gap | 2.257 | -6.310 | 0.885 | 0.140 |
| Neighbor distance | 0.0441 | -6.310 | 30.052 | 0.835 |
| Edge distance | 1.902 | -25.325 | 18.364 | 0.175 |
| Year of intro | 0.701 | 0.0242 | 0.0289 | 0.407 |
| Native congener | 0.001 | 11.409 | 597.623 | 0.985 |
| NIS congener | 0.822 | -0.626 | 0.691 | 0.369 |

## Discussion

Propagule size has an obvious influence on invasion success, as do other obvious factors such as ease of transportation (Williamson 1996). A propagule size of one produces no possibility of establishment except with parthenogenic species or a pregnant female. The relationship between propagule and successful establishment asymptotes quickly (Pimm 1991). I attempted to eliminate the effect of propagule size from this model, and consider only those species introduced with a sufficient propagule for establishment. Despite data of relatively high quality, some unsurety exists in classifying species, thus I used two interpretations for unsuccessful species introduced with a large enough propagule for possible establishment.

The differentiation of introduced species and invasive species obscures the problem of biological change associated with non-indigenous species. This analysis

included only introduced species, only because it is not possible to consider unsuccessful invasive species in the context of our model. Invasions by non-indigenous "native species" such as the Brown-headed Cowbird (*Molothrus ater*) and coyote (*Canis latrans*) may be as ecologically damaging as the effects of classic "introduced" species, and are equally relevant when considering the ecology and impact of non-indigenous species. I would be remiss to consider the one without the other. The results of Chapter 2 demonstrated that both invasive and introduced species follow the same pattern in success in the context of vertebrate community structure, and suggested that landscape-level change, rather than intrinsic traits of invaders or even community level interactions, predicts invasion success better than intrinsic species traits.

In the study of biological invasions, the search for predictability of success has been hampered by extrapolation from single species studies and the adherence to one or another competing hypotheses of single causation. Multiple causes are responsible for the success of invasive species and these include introduction effort (a variable only of interest in species translocations), anthropogenic and other landscape-level changes, intrinsic traits of invasive species, community properties such as saturation, and the scale of perturbation and species environmental use. The consideration of invasions without explicitly defining the scale of resource exploitation of species and disturbance are unlikely to provide paradigms useful for resource managers or ecologists.

Intrinsic traits of species fail to offer a satisfactory paradigm for predicting invasions (see Chapter 1). Community level traits often fail to account for scale. For example, congeners that might be expected to strongly interact on the basis of

phylogenetic similarity may interact very little if they exploit the environment at different ranges of scale (Peterson et al. 1998). The same criticisms may be applied to variables associated with invaded habitats, especially the strong correlation between invasions and habitat disturbance. The paradigm that disturbed habitats are more likely to be invaded (Elton 1958) is one of the few definite associations established by the study of biological invasions, but the definition of disturbance is elusive, and should be scale bound. For example, consider mosquito ditching on the Florida Keys. Mosquito ditches, dug for the control of mosquitoes, are a very local and small-scale disturbance. For a species interacting with the environment at a very large scale - e.g., black bears, such a disturbance may be irrelevant. For a species that operates at a small scale, such as the non-indigenous red imported fire ant, such a disturbance is a major perturbation, and rapidly exploited. The lack of scale in definitions of disturbance creates a concept so vague and universal that it is hard to refute. What constitutes a disturbance to one species may be below, or above, the range of perception for another.

I have constructed a conceptual model of invasion success that takes into account species, communities, and landscapes. Multiple analysis and lines of evidence support the hypothesis originally proposed by Holling (1992) that vertebrate assemblages are entrained by the scale specific pattern of resource distribution within and across scales (Holling 1992, Restrepo et al. 1997, Lambert and Holling 1998). I demonstrated that non-indigenous species (and declining native species) are most likely to occur at the edge of lumps, at least in transforming landscapes. I hypothesized that gaps in the distribution represent phase transitions between distinct

ranges of scale, and may be considered zones of both crisis and opportunity for species whose body masses place them at the edge of these phase transitions.

I suggest that the first determinant of vertebrate community structure is the landscape, and specifically the scale-specific and discontinuous distribution of resources within and across scales (Holling et al. 1995). This leads to what has been termed a "lump and gap" architecture in vertebrate communities, the segregation of communities into distinct groupings (lumps). Species within a particular lump operate at similar ranges of scale. Lumps of species are strongly interacting, with the result that species exploiting the same resource in a similar way tend not to occur in the same lump (Peterson et al. 1998). In other words, potential strong competitors (e.g., members of the same functional guild or group) tend to coexist by exploiting their environment at different scales. The end result of this is maximized functional diversity within a range of scale, and functional redundancy across scales (Peterson et al. 1998). Such a proposition needs further testing, and this is done in Chapter 7.

Scale-specific community structure - constancy of ratio within lumps (see Chapter 7) and redundancy of species function across scales - is suggestive of competitive interactions. This suggests that the south Florida (and probably most mainland faunas) may be considered saturated. Perturbations affecting key landscape structuring processes (in south Florida, the alteration of hydrologic and fire regimes accelerated by the establishment of non-indigenous plant species) cause a direct change in ecological structure. If the distribution of ecological patterns within and across scales entrains vertebrate communities, the expected result of systemic perturbations are simultaneous events of invasion and extinction. Because scale

breaks offer chaotic or highly variable resources, it is here that we expect to see events of extinction and invasion. Within lumps of species, competitive interactions may lessen the probability of invasion.

Other investigations indicating a priority effect considered the mean number of species present (MSP; Moulton and Sanderson 1997) at the time of each successive introduction. I used years before present because I envision the avian community of south Florida to be saturated or near saturation. We are witnessing a species turnover (not replacement) in that system driven by anthropogenic alteration of key structuring processes. As new processes take over, a time lag is expected before new ecological patterns become dominant on the landscape. The loss of native species and addition of non-indigenous species is expected to further entrench landscape-level change. These changes are expected to create a new system state in the Everglades Ecoregion, structured around a new set of processes with new periodicities, from which it will be difficult to re-establish the original ecosystem.

# CHAPTER 4
# THE SOUTH FLORIDA VERTEBRATE COMMUNITY THROUGH TIME

## Introduction

The biological phenomenon of invasion and extinction may be predictable by understanding the impacts of anthropogenic and natural perturbations on ecosystem structuring processes, the resilience of various ecosystems and their ecological structure to perturbations, and the forces which structure vertebrate communities. The clustering of the biological extrema represented by invasions and extinctions at the edge of body mass lumps suggests variability of resources, of one kind or another, at scale breaks.

Analysis of the patterns of invasion and deletion in terms of lump and gap architecture suggested variability in resource availability at lump edges. If so, it may be expected that other forms of biological variation also are more pronounced at body mass lump edges. This has been suggested with some preliminary analyses of several different data sets.

All communities experience temporal turnover in species composition at short and long-term intervals. Longer-term temporal change is represented by invasions and extinctions. Short-term and regular annual turnover in species composition occurs in birds with changes in the breeding and wintering fauna. South Florida has relatively

few species which are not permanent residents, but several species do migrate out of the region at the approach of winter, and south Florida does support a large migratory component of non-breeders during winter.

Data from the south Florida Everglades ecosystem provided an opportunity to test hypotheses related to temporal change in species turnover in relation to community structure. Longer-term changes caused by biological invasions and extinctions could change community structure in a number of ways, with hypotheses paralleling those of Chapter 2, Figure 2-2. Chapter 2 considered the competing hypotheses that 1) invasions and deletions could be random, 2) could occur in lumps, 3) occur in gaps, 4) occur at a single scale range, or 5) could occur at the transitions representing scale breaks. The hypothesis that the biological phenomenon of invasion and extinction were related to scale breaks was supported. However, testing for differences between community structure in pre-invasion and hypothetical post-invasion faunas provides an analysis of those hypothesis in a completely different context. The comparison on pre- versus post-invasion community structure further tests the hypothesis that invasions and extinctions occur at body mass lump edges (Chapters 2 and 3). The significance of presence in gap versus lump presented in Chapter 3 suggests that invasions may be occurring at gaps in the vertebrate community, rather than at the gap/lump interface. If invasive species are filling in the gaps, as partially suggested by the logistic regression model in Chapter 3, then post-invasion community structure would be continuous, that is, the lumpy nature of the vertebrate body mass distributions would be lost, or at least greatly altered.

Shorter-term changes in community structure, and the pattern of those changes, is provided by analysis of the south Florida breeding and wintering avifuana. Given the results of chapter 2, one may expect that population turnover represented by migration would occur mostly at body mass lump edges. In the context of body mass lump structure, an investigation of the location of migratory species versus permanent residents provides a test of the hypothesis that migratory species tend to be associated with scale breaks. This chapter tests whether the south Florida vertebrate community structure changes after extinction and invasion events, and whether the annual loss of avian species from south Florida is associated with body mass lump edges.

## Methods

### Changes over time

The comparisons between historic and future vertebrate community structure were made visually and statistically. Historic structure was considered the extant fauna at the time of European colonization. Species that are now extinct in the south Florida ecosystem were included (e.g., red wolf, *Canis rufus*, Carolina Parakeet, *Conuropsis carolinensis*), but non-indigenous species were omitted. Future vertebrate communities were constructed by including established non-indigenous species and omitting all recently extinct or listed species (see Appendix B). Historic and future community structure was determined using a null model in combination with computer simulation, as described in Chapter 2.

To statistically compare historic and future communities, body mass axes for each vertebrate group were divided into 0.01 (log scale) bins. A binary variable was

assigned to each 0.01 log10 gram bin, where 1 represented a lump and 0 represented a gap. The smallest and largest species in each comparison provided the limits for the binary variables. That is, comparisons were made only in the range of shared data. The similarity of within taxa historic - future community structure was then compared in a 2 x 2 table with the chi-square statistic. In that case, the null hypothesis is that there are equal distributions of the variables among the four cells (both data sets in the lump condition, both data sets in the gap condition, one data set in the lump condition while the other in gap condition, and vice versa), that is the two groups are unrelated. Phi correlation, a correlation of binary variables, also was made for each historic - future comparison. The Phi coefficient ranges from -1 to 1. Values approaching -1 are strongly negatively correlated and values approaching 1 a strongly positively correlated. Phi correlation has no associated probability level, but Fleiss (1981) suggested that a value of greater than ± 0.30 are "significant".

Annual changes

The south Florida Everglades ecosystem avifauna was used to test whether migrant bird species were associated with body mass lump edges. The data used were identical to that in Chapter 2 (Appendix B). Species were categorized as migratory or permanent residents. Permanent residents summered and bred in the south Florida ecosystem and regularly wintered there. Migrants summered and bred in the south Florida ecosystem, but migrated the West Indies, Central or South America for the winter. Categorization of species was based on Stevenson and Anderson (1994) as well as maps produced by the Florida Biodiversity Project and reviewed by several Florida ornithologists (C. R. Allen, Florida Biodiversity Project, *unpublished data*).

To test the hypothesis that migratory species had body masses that associated them with body mass lump edges, I calculated the distance of every species to the nearest body mass lump edge in terms of log10 body mass. The distance to edge distributions for permanent resident birds and migratory birds were compared with the Mann-Whitney Rank Sum Test because the data were not normally distributed and had unequal variances.

## Results

### Changes over time

Species turnover in historic - future comparisons was high because nearly 25% of the vertebrates of south Florida are listed as threatened, endangered, or a species of special concern, and because about 25% of the present breeding fauna is represented by established non-indigenous species. Despite the relatively large change in species compositions between these comparisons, community structure changed little. Figure 4-1 graphically displays the comparisons for each vertebrate group.

In all three comparisons the null hypothesis of no relationship between compared data sets was rejected (Tables 4-1, 4-2, 4-3). Future community structure will be very similar to historic structure; invasive species do not fill in the gaps, and gap and lump structure remains little changed. Phi coefficients were positive in all comparisons, but ranged from relatively low for mammals (Phi = 0.164) to very high for birds (Phi = .588). Concordance between the historic versus future comparisons was 84% for birds, 68% for herpetofauna, and 60% for mammals.

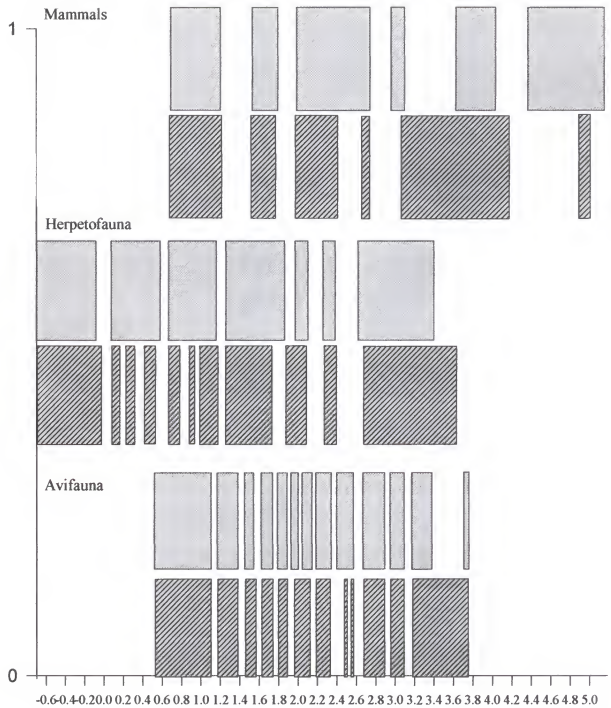


Figure 4-1. Historic - future comparisons of the south Florida vertebrate community structures. Grey-shaded distributions represent the historic community structure, and cross-hatched distributions represent future structure.

Table 4-1. Chi-square and Phi coefficients for the comparison of historic to future avifauna in the south Florida Everglades ecosystem. Listed in the body of the table are n for each of the 4 possible states and percent of binary variables in each state. Historic structure is as described in Chapter 2 and found in Appendix B and as Figures 2-3, 2-4, 2-5, and includes native fauna recently extinct but no post European colonization invasive species. Historic structure was determined by removing listed species and including established invasive species. Lump structure was turned into a one-dimensional binary variable (n=327), coded as 0 for gap and 1 for lump.

| | Gap | Lump | Chi-square | P | Phi |
|---|---|---|---|---|---|
| Gap | 56 (17%) | 40 (12%) | | | |
| Lump | 13 (4%) | 218 (67%) | 113 | <0.001 | 0.588 |

Table 4-2. Chi-square and Phi coefficients for the comparison of historic to future herpetofauna in the south Florida Everglades ecosystem. Listed in the body of the table are n for each of the 4 possible states and percent of binary variables in each state. Historic structure is as described in Chapter 2 and found in Appendix B and as Figures 2-3, 2-4, 2-5, and includes native fauna recently extinct but no post European colonization invasive species. Historic structure was determined by removing listed species and including established invasive species. Lump structure was turned into a one-dimensional binary variable (n=434), coded as 0 for gap and 1 for lump.

| | Gap | Lump | Chi-square | P | Phi |
|---|---|---|---|---|---|
| Gap | 62 (14%) | 77 (18%) | | | |
| Lump | 62 (14%) | 233 (54%) | 26 | <0.001 | 0.244 |

Table 4-3. Chi-square and Phi coefficients for the comparison of historic to future mammal fauna in the south Florida Everglades ecosystem. Listed in the body of the table are n for each of the 4 possible states and percent of binary variables in each state. Historic structure is as described in Chapter 2 and shown in chapter 2 as Figures 2-3, 2-4, and 2-5, and include native fauna recently extinct but no post-colonial invasive species. Historic structure was determined by removing listed species and including established invasive species. Lump structure was turned into a one-dimensional binary variable (n=444), coded as 0 for gap and 1 for lump.

| | Gap | Lump | Chi-sq | P | Phi |
|---|---|---|---|---|---|
| Gap | 87 (20%) | 70 (16%) | | | |
| Lump | 110 (25%) | 177 (40%) | 12 | <0.001 | 0.164 |

Annual changes

Of the 106 breeding bird species in south Florida, ten were categorized as migratory while the remaining 96 both breed and winter there. The distance to body mass edge distributions of these two groups were significantly different (Table 4-4). Migratory species had body masses that placed them an order of magnitude closer to body mass lump edges.

Table 4-4. Comparison between the distribution of distance to nearest body mass lump edge for migratory (breeding species that winter elsewhere) and permanent resident avifauna of the south Florida Everglades ecosystem. One-tailed Mann-Whitney U statistic (T), number of observations (N) and probability (P) are given for comparisons of the relative distance from a body mass lump edge between the two groups.

| Class | Median edge distance | N | T | P |
|---|---|---|---|---|
| Migratory | 0.00133 | 10 | | |
| Permanent residents | 0.0108 | 96 | 374.0 | 0.042 |

## Discussion

The hypothesis that temporal change in species composition is most pronounced at body mass lumps was supported by the analysis of historic - future vertebrate structure and the proximity of migratory bird species to body mass lump edges. Body mass lump structure changed little after a > 25% turnover in species, as represented by analysis of pre-invasion native faunas versus post-invasion hypothetically constructed faunas.

The lack of significant changes in lump structure despite a large species turnover supports the hypothesis of chapter 2 that invasions and extinctions occur at scale breaks. One alternative hypothesis was that invasions occur at body mass gaps. If that were the case, I would be further documenting the occurrence of morphological overdispersion, well documented for several introduced island avifaunas. However, in this case gaps are not filled; rather, invasions (and declines as documented in Chapter 2 and supported by this analysis) occur at the edge of lumps, the area between distinct ranges of scale.

Migratory components of the south Florida avifauna were located closer to body mass lump edges than permanent residents. The difference between median distance to body mass lump between migratory and non-migratory species was significant despite the very lower power of the tests used (power < 0.05). This finding also supports the hypothesis of Wiens (1989) that chaotic or highly variable phenomena are expected at scale breaks in biological communities. These results

provide further support for that hypothesis and, with the results of the analyses described in earlier chapters, provides the first quantitative support for that proposition.

These results, and those of earlier chapters, suggest a new model of community assembly, and support the proposed theoretical model of the relationship among biological diversity, scale and ecological resilience presented in Peterson et al. (1998). It suggests scale specific groupings of species that interact strongly within a scale and less strongly across scales. The findings of this and previous chapters strongly support the deliniation of vertebrate communities into scale specific groupings, separated by distinct breaks and characterized by variability at scale breaks. After further testing the relationship between ecological processes, ecological structure and vertebrate community structure, as well as further testing the relationship between invasions, declines, and variability at scale breaks, I present a model of community assembly in Chapter 7.

# CHAPTER 5
# PATTERNS IN STRUCURE AND INVASION IN GLOBAL MEDITERRANEAN-CLIMATE ECOSYSTEMS

## Introduction

Mediterranean-climate ecosystems have been well studied because of their ecological similarities in process, function, and structure, despite extreme biological isolation (e.g., Mooney 1977, Kalin Arroyo et al. 1995, Davis and Richardson 1995, Moreno and Oechel 1995). They occur largely on separate continents, in coastal California, central coastal Chile, the southern tip of South Africa, in a coastal belt around the Mediterranean basin, and in two disparate locations in southern Australia; the extreme southwestern tip and in the Adalaide region in southcentral Australia. The geographic histories among the areas are distinct. The South African and Australian landscapes are older than the other three mediterranean-climate regions, and soils differ among all sites (Hobbs et al. 1995). Despite extreme geographic and evolutionary isolation, mediterranean climate ecosystems show similarity at several scales, for instance leaf structure of many of the fire adapted shrubs (Mooney 1977, Cody and Mooney 1978) and overall physiognomy of the vegetation (Mooney and Dunn 1970). Also, at very broad scales, these regions are similar in landcover, and the landcover is structured by many of the same general processes, especially fire. In general, these ecosystems are characterized by winter rains with a pronounced dry-

season and frequent fires. Vegetation is largely fire-adapted grassland and brush land under various local names including Chaparral (California), Mallee (Australia), and Fynbos (South Africa). Deliniation of mediterranean-climate regions varies by author, and especially whether one considers primarily climatic or vegetative boundaries. Cody (1986) defines mediterranean climate regions as areas with low precipitation (275-900mm) falling primarily during the cool winters, with warm dry summers.

These regions are especially interesting to ecologists and conservation biologists for a variety of reasons, including the ecological convergence mentioned above. These areas are biologically rich, with a relatively high level of endemism (Blondel and Aronson 1995). Additionally, many of the climatic factors that define these regions also make them suitable for a wide variety of agriculture and other associated human endeavors. Mediterranean-climate regions support large human populations, resulting in extensive, and outside the Mediterranean Basin proper, rapid, anthropogenic transformation. Compared to other continental areas, mediterranean regions have been invaded by a large number of non-indigenous organisms, including vertebrates.

Because of a general similarity in landscape structure, at least at some scales, mediterranean-climate ecosystems provide a unique opportunity to compare similarities in scale specific vertebrate community structure, that is the lump and gap architecture of the vertebrate communities. These regions have isolated and dissimilar vertebrate communities but are structured by similar processes and have similar vegetative physiognomies. Holling (1992) proposed that the lump structure of given ecosystems reflected entrainment to the scale specific pattern of an ecosystem. The

entrainment hypothesis was supported while several competing hypotheses were rejected (Holling 1992). Scale-specific vertebrate lump structure among ecosystems differs, because the processes responsible for producing scale-specific patterns in landscapes differ. Mediterranean-climate ecosystems, because of their supposed similarity in structure should share similar vertebrate lump structures despite the geographic and evolutionary isolation of the vertebrate faunas.

The purpose of this chapter is to compare the vertebrate lump structures among the various mediterranean-climate ecosystems. If the vertebrate lump structures among the systems are similar, the entrainment hypothesis of Holling is strongly supported. Additionally, the relatively large number of successful invasions by vertebrates in mediterranean-climate ecosystems provides an opportunity to further test the association of invasive species with scale breaks (Chapter 2).

## Methods

### Data sources

Data were compiled from a variety of reliable sources, but data quality not unexpectedly varied by region and taxa. Mediterranean-climate Californian (chaparral) mammals were determined from a specific study of the habitat preferences and distribution of mammals in that habitat (Quinn 1990). Chaparral birds were determined from two sources, providing data for two separate analyses. Unitt (1984) provided a thorough list of the birds of San Diego county. This list was used because it provided specific data on abundance and migratory status, used in other chapters. As with other bird lists, pelagic and non-breeding species were not used in my

analyses. Species restricted to highland conifers and coastal lowlands were omitted from the San Diego list. The California data set was published by Vuilleumier (1991). Of the 298 species on the combined lists of California and San Diego, 97 were common to both. To some degree, the San Diego list was a subset of the California list.

Vuilleumier (1991) also provided a list of the birds of mediterranean-climate Chile in his comparison of the avifaunas of California and Chile. Because the composition of these disparate avifaunas came from the same source, they may be the most comparable. The list of Chilean mammals came from Miller (1980), who provided both a list and data on abundance and changes in species composition over time. Data from Redford and Eisenberg (1981) provided collaboration of the Miller data.

Asia Minor (Turkey), Iberian, and Greek mammal data sets came from Cheylan (1991). Mediterranean-climate bird lists for Spain and Turkey were compiled from the comprehensive work of Cramp (1978, 1983a, 1983b, 1984, 1988, 1992, 1993, 1994a, 1994b).

Mammals residing in the mediterranean-climate Fynbos of the southern cape of South Africa were determined from Smithers (1983). As with other data sets, peripheral species were omitted. The data in Bigalke (1979) was used to confirm the species list I compiled from Smithers. Bird data used was that of Winterbottom (1966), who extensively studied the avifauna of mediterranean shrublands in the cape of South Africa.

Mammal data for the two mediterranean-climate regions of Australia were compiled from Strahan (1995) who provided excellent distribution maps, for both extant and recently extinct or extirpated species. The list of southwestern Australian birds was found in Saunders and Ingram (1995), who wrote a publication specific to the avifauna of southwestern Australia. A list of the mediterranean-climate birds of southcentral Australia was found in Schodde (1981).

Data on the occurrence of non-indigenous birds and mammals also was gathered from the above sources, although data on non-indigenous species was not available for all sites (see below). Data on non-indigenous birds in the Fynbos of South Africa was from Brooke et al. (1986).

Body-mass estimates

In nearly all cases body mass estimates came from Dunning (1993) for birds and (Silva and Downing 1995) for mammals. Where possible, mass estimates from the region of interest were preferentially used. Where that was not possible, estimates were taken from the nearest geographic location. Male and female mass estimates were averaged when weights for both sexes were provided. For birds, exceptions to the use of Dunning (1993) included the bird species lists from the Mediterranean Basin (Spain and Turkey). For those sites, estimates published in (Cramp1978, 1983a, 1983b, 1984, 1988, 1992, 1993, 1994a, 1994b ) were utilized, and usually specific to the region. Weights for mammals of mediterranean-climate Chile were primarily from Redford and Eisenberg (1981), because mass estimates for a number of species could not be found in Dunning (1993). Body mass estimates for Australian mammals were from Strahan (1995).

Analysis of mediterranean-climate vertebrate community structure

Lump and gap architecture of the vertebrate communities in question was determined as described in chapter 2. Species without an available, reliable, body mass estimate were removed from the lists prior to analysis (Appendices E and F). My goal was to determine the similarity of bird and mammal fauna structures among the various mediterranean-climate ecosystems. However, lump structure is determined along a single axis (log10 body mass), and consists of a single dichotomous variable (body mass lump or body mass gap) along the single axis. There is no accepted methodology for determining patterns among multiple data sets for data of this type. Instead, I proceeded as in Chapter 4, and made all possible pairwise comparisons among the data. Specifically I used a chi-square analysis to test whether the comparisons differed from the null condition - that of equal distribution of the dichotomous variables among four possible states, in agreement (both data sets compared at a gap along the body mass axis or both at a lump) or disagreement (data set A in gap state while B in a lump state, and vice versa). To provide additional information, I also compared percentage of the variables in agreement and Phi coefficients. All comparisons were made by first dividing the log10 body mass axis into 0.01 increments, and then assigning each increment to either a 0 or 1 condition, with 0 representing a gap and 1 representing a lump. Upper and lower extremes for each comparison were determined by the largest and smallest body masses for species in the comparison.

Invasions in mediterranean-climate ecosystems

Analysis of the distribution of non-indigenous species in mediterranean-climate ecosystems depended on first determining the lump structure of the native species in the different systems. The methodology used was identical to that described in Chapter 2, and the interpretation used was the same as for the analysis described above (Appendices E and F). The criteria line for determining significant discontinuities was varied based on species richness (sample size) to maintain a power level of approximately 0.50. The observed number of non-indigenous species occurring at body mass gaps was compared to expected values that were based on the number of non-indigenous species and the number of discontinuities in an ecosystem. Data on invasions were not present for all ecosystems. Mammal data were used from the following mediterranean-climate ecosystems: California, Chile, Greece, South Africa, southwestern Australia, and southcentral Australia. Bird data were used from these systems: California, Chile, South Africa, Spain, Turkey, and southwestern Australia. In analyses, values from different ecosystems within a single vertebrate taxa (i.e., birds or mammals) were used as replicates. The determination of observed and expected values and overall analysis was conducted as described in Chapter 2. As in that analysis, $X^2$ analyses were conducted (rather than an exact test) because the result of >20% of expected values falling below 3 was a small decrease in power, increasing the conservative nature of the tests.

## Results

### Analysis of mediterranean-climate vertebrate community structure

All vertebrate data sets were discontinuous. The number of body mass lumps in mammal data sets from mediterranean climate ecosystems varied from 4 (Chile) to 9 (South Africa). The average number of lumps was 6.5. In birds, the number of body mass lumps varied from 8 (Turkey) to 16 (both California and southwestern Australia), with an average of 12.4. The lump structure of mediterranean-climate bird communities is shown if Figure 5-1. The structure of mediterranean-climate mammal communities is shown in Figure 5-2. Some similarities are apparent among different ecoystems (e.g., the mammal and bird faunas of Chile and California), but a clear similarity among all sites is not visually apparent.

The similarity among data sets was determined quantitatively by making all possible pairwise comparisons. Species richness and bin total number of bins (i.e., the number of 0.01 increments between the smallest and largest member of a given community) varied among sites (Table 5-1), but richness and total number of bins were not related ($r = 0.601$, $P = 0.115$).

A total of 28 pairwise comparisons were possible among the eight mediterranean-climate avifaunas. Nineteen of those comparisons were significant, that is the compared avifaunas had similar patterns in their lump structure. Five of the non-significant comparisons involved the South African fauna (Table 5-2).

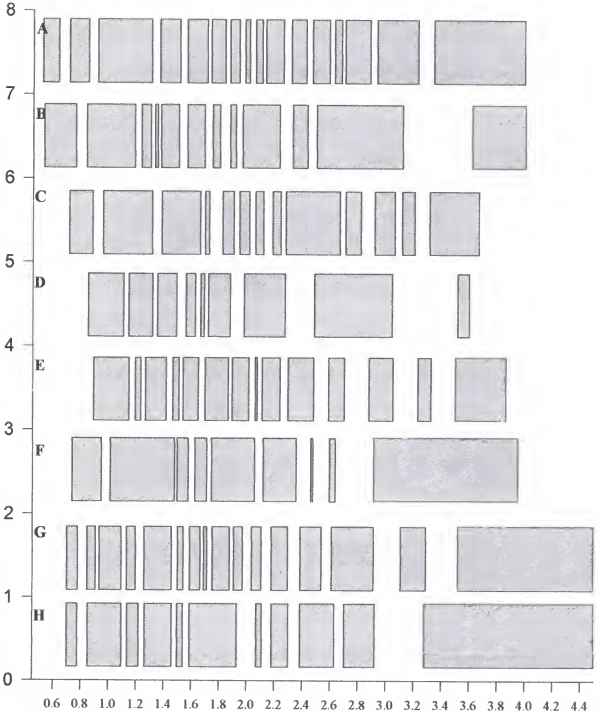


Figure 5-1. Lump structure of mediterranean-climate birds. A = California, B = San Diego, C = Chile, D = South Africa, E = Spain, F = Turkey, G = Southwestern Australia, and H = Southcentral Australia.

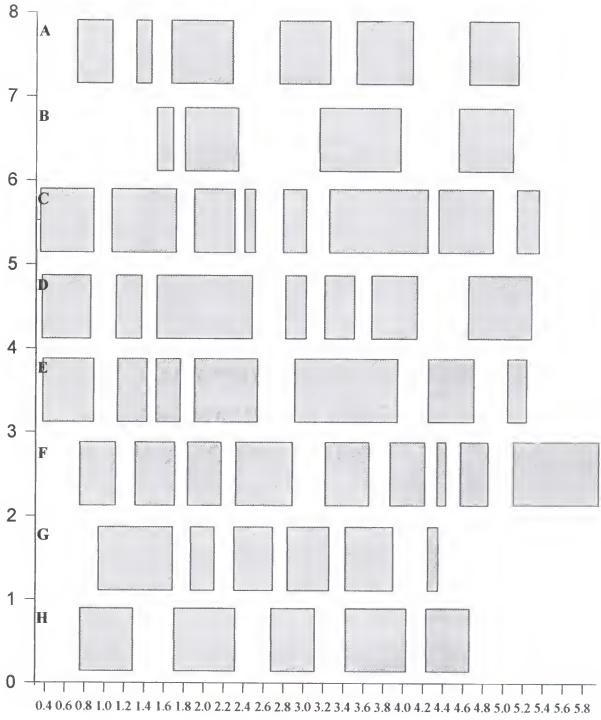


Figure 5-2. Lump structure of mediterranean-climate mammals. A = California, B = Chile, C = Turkey, D = Spain, E = Greece, F = South Africa, G = Southwestern Australia, and H = Southcentral Australia.

Table 5-1. Number of bins resulting from dividing the body mass axis of each mediterranean-climate ecosystem avifauna into 0.01 log10 unit increments, with upper and lower limits determined by the minimum and maximum body mass present in the native fauna. Richness is the number of bird species in each mediterranean-climate ecosystem.

| | Bins | Richness |
|---|---|---|
| CALIFORNIA | 352 | 181 |
| SAN DIEGO COUNTY | 352 | 117 |
| CHILE | 296 | 107 |
| SOUTH AFRICA | 274 | 91 |
| SPAIN | 299 | 119 |
| TURKEY | 325 | 104 |
| SOUTHWESTERN AUSTRALIA | 379 | 141 |
| SOUTHCENTRAL AUSTRALIA | 379 | 124 |

Table 5-2. Pairwise comparisons among mediterranean-climate ecosystem avifaunas. The body of the table is composed of chi-square probability levels for each comparisons. Probability levels less than or equal to 0.05 were considered significant matches between the lump and gap architecture of the compared systems. CAL = California, SDI = San Diego county, CHI = Chile, SAF = South Africa, SPA = Spain, TUR = Turkey, SWA = southwestern Australia, and SCA = southcentral Australia.

| | CAL | SDI | CHI | SAF | SPA | TUR | SWA | SCA |
|---|---|---|---|---|---|---|---|---|
| CAL | --- | 0.001 | 0.050 | 0.295 | 0.061 | 0.437 | 0.014 | 0.016 |
| SDI | --- | --- | 0.002 | 0.001 | 0.374 | 0.001 | 0.131 | 0.001 |
| CHI | --- | --- | --- | 0.804 | 0.031 | 0.003 | 0.016 | 0.014 |
| SAF | --- | --- | --- | --- | 0.633 | 0.001 | 0.953 | 0.266 |
| SPA | --- | --- | --- | --- | --- | 0.029 | 0.043 | 0.066 |
| TUR | --- | --- | --- | --- | --- | --- | 0.001 | 0.001 |
| SWA | --- | --- | --- | --- | --- | --- | --- | 0.001 |
| SCA | --- | --- | --- | --- | --- | --- | --- | --- |

The percent of the dichotomous variables (0, gap or 1, lump) in agreement were important. I considered comparisons where >50% of the bins were in agreement to indicate a reasonably good match between the lump structure of the compared

ecosystems. Seventeen of the possible 28 pairwise comparisons were in agreement over at least 50% of their combined range (Table 5-3). Comparisons where there was a degree of species overlap had the highest correspondence. These comparisons included the California data with the San Diego data (77% agreement), and southwestern Australia with southcentral Australia (79% agreement). Other comparisons with a relatively high level of correspondence included California and Chile, San Diego and South Africa, and California and Turkey. Phi coefficients among the comparisons were generally low, indicating weak relationships (Table 5-4).

Table 5-3. Pairwise comparisons among mediterranean-climate ecosystem avifaunas. The body of the table is composed of the percentage of the dichotomous variable in agreement (i.e., lump versus gap) between the two compared systems. CAL = California, SDI = San Diego county, CHI = Chile, SAF = South Africa, SPA = Spain, TUR = Turkey, SWA = southwestern Australia, and SCA = southcentral Australia.

| | CAL | SDI | CHI | SAF | SPA | TUR | SWA | SCA |
|---|---|---|---|---|---|---|---|---|
| CAL | --- | 77 | 61 | 52 | 50 | 65 | 52 | 54 |
| SDI | --- | --- | 49 | 61 | 52 | 53 | 52 | 46 |
| CHI | --- | --- | --- | 54 | 51 | 54 | 48 | 49 |
| SAF | --- | --- | --- | --- | 52 | 42 | 48 | 45 |
| SPA | --- | --- | --- | --- | --- | 62 | 47 | 48 |
| TUR | --- | --- | --- | --- | --- | --- | 47 | 48 |
| SWA | --- | --- | --- | --- | --- | --- | --- | 79 |
| SCA | --- | --- | --- | --- | --- | --- | --- | --- |

Table 5-4. Pairwise comparisons among mediterranean-climate ecosystem avifaunas. The body of the table is composed of phi coefficients for each comparisons. CAL = California, SDI = San Diego county, CHI = Chile, SAF = South Africa, SPA = Spain, TUR = Turkey, SWA = southwestern Australia, and SCA = southcentral Australia.

| | CAL | SDI | CHI | SAF | SPA | TUR | SWA | SCA |
|---|---|---|---|---|---|---|---|---|
| CAL | --- | 0.367 | 0.104 | 0.056 | -0.100 | 0.041 | -0.123 | -0.120 |
| SDI | --- | --- | -0.168 | 0.254 | -0.047 | -0.218 | -0.075 | -0.253 |
| CHI | --- | --- | --- | -0.014 | -0.121 | -0.162 | -0.124 | -0.126 |
| SAF | --- | --- | --- | --- | -0.028 | -0.256 | -0.003 | -0.057 |
| SPA | --- | --- | --- | --- | --- | 0.121 | -0.104 | -0.095 |
| TUR | --- | --- | --- | --- | --- | --- | -0.279 | -0.301 |
| SWA | --- | --- | --- | --- | --- | --- | --- | 0.443 |
| SCA | --- | --- | --- | --- | --- | --- | --- | --- |

Invasions in mediterranean-climate ecosystems

All mediterranean-climate ecosystems have been invaded by non-indigenous vertebrates to varying degrees. However, the Mediterranean Basin proper has experienced fewer invasions, at least in the last several centuries, and often has been the source for non-indigenous species established elsewhere (Groves and di Castri 1991). Chile and southcentral Australia had the largest number of successful non-indigenous mammal species (Appendix F and Table 5-5), while California had the largest number of successful non-indigenous birds (Appendix E and Table 5-5).

Successful invasions were non-random in terms of community lump structure. Successful non-indigenous species tended to occur at body mass gaps in both mammals ($P < .0001$) and birds ($P < .0001$). Forty percent of the established non-indigenous mammals and 31% of the established non-indigenous birds occurred at the edge of body mass lumps. Only in South Africa (for mammals) and in Turkey (for birds) were expected values higher than observed values. The total number of avian

invasions in Turkey was very low. On average, observed values were nearly three times larger than expected values for both mammals and birds.

Table 5-5. Number (N) of established non-invasive species, observed (Obs.), expected (Exp.), and probability values (P) of $X^2$ tests of association of invasive species with body mass lump edges.

| | Location | N | Obs. | Exp. | P |
|---|---|---|---|---|---|
| MAMMALS | California | 2 | 2 | 0.38 | |
| | Chile | 11 | 5 | 1.63 | |
| | Greece | 4 | 2 | 0.58 | |
| | South Africa | 8 | 1 | 1.11 | |
| | Southwestern Australia | 8 | 2 | 1.14 | |
| | Southcentral Australia | 10 | 5 | 1.61 | 0.0001 |
| BIRDS | California | 18 | 3 | 1.59 | |
| | Chile | 7 | 2 | 0.85 | |
| | South Africa | 8 | 5 | 0.89 | |
| | Spain | 4 | 1 | 0.47 | |
| | Turkey | 3 | 0 | 0.29 | |
| | Southwestern Australia | 9 | 4 | 1.02 | 0.0001 |

## Discussion

Despite several inherent methodological problems mediterranean-climate faunas have similar lump structures, though the match does not provide unequivical support for the entrainment theory of Holling (1992). Despite numerous publications citing convergence among mediterranean-climate regions, many differences exist among the regions. Differences in geologic histories and soils are pronounced (Hobbs et al. 1995). Total rainfall and the timing of that rainfall differs substantially among regions (Versfeld et al. 1992). Anthropogenic transformation has been severe in all

mediterranean landscapes, but the nature of that impact varies. The Mediterranean Basin proper has had a long history of human impact dating to at least 10,000 years before present (Naveh and Kutiel 1990). Australia has been impacted by large-scale anthropogenic transformation most recently (Hobbs et al. 1995), but that impact has been rapid and severe (Saunders and Ingram 1995). Additionally, the nature of anthropogenic impacts varies greatly among sites, and includes grazing impacts, transformation to agriculture, removal of forest cover, planting of exotic trees, elimination of herbivorous megafauna, varying degrees of invasion by exotic plants and animals, and varying impacts on fire regimes (Hobbs et al. 1995). The supposition of cross-scale convergence also has been recently questioned. Barbour and Minnich (1990) highlight the differences among the regions. These include gross differences in vegetation types, physiognomy, leaf spectra, species richness, morphological adaptation, phenology, and overall biomass and productivity.

Problems in the comparison of patterns among sites also are related to the delineation of mediterranean-climate regions, determination of pattern in vertebrate communities and the lack of powerful methodologies for the comparison of pattern. The boundaries of mediterranean-climate regions are not clearly obvious. Differences arise when different authors use different criteria to determine ecosystem boundaries, a problem inherent in the delineation of ecosystem boundaries in general. The use of vegetative versus climatic criteria has a large influence on the delineation of mediterranean-climate ecosystem limits, and those limits influence the resulting lists of species composition. I attempted to use a consistent criteria where I determined species lists from larger compendia (e.g., most of the mediterranean basin, Australia

mammals), but the definitions used by the authors of system-specific lists varied. Determination of lump structure also remains inexact, especially at the extremes (upper and lower body mass limits) of body mass distributions. I used an objective method for determining the structure present in vertebrate communities, but this may be overly conservative. An examination of the data in Appendices E and F reveals probable breaks that were missed in the analyses. Comparison of pattern in the analysis of serial data remains largely ignored by statisticians. The methods employed are not powerful, and the interpretation of coefficients associated with phi correlation remain vague.

Despite the problems mentioned above, a fair correspondence exists among the vertebrate structure of mediterranean-climate ecosystems. The relative correspondence among mediterranean-climate vertebrate structure may be best understood by comparing these structures with the vertebrate structure of south Florida faunas. Sendzemir (1998) compared vertebrate lump structure among and between biomes, and demonstrated a correspondence within biomes but poor correspondence between biomes. That source provides an analysis of multiple data sets from around the globe, and comparisons of their structures with mediterranean structures provides further evidence of a degree of similarity among mediterranean-climate ecosystems.

Successful establishment of non-indigenous species in mediterranean-climate ecosystems is strongly non-random, and further supports the hypothesis of chapter 2. More than three times as many invasive species had body masses that placed them at lump edges than were expected if they were randomly distributed. Forty percent of

successful mammalian invasions and a third of avian invasions occurred at the edge of body mass gaps. Removing sources of potential redundancy (i.e., either of the two Australian mammal data sets and either of the two Mediterranean Basin avian data sets) does not affect the results. A large percentage of successful vertebrate invaders have body masses that place them at scale breaks in the community structure.

# CHAPTER SIX
# RARITY, ABUNDANCE AND NOMADISM IN RELATION TO SCALE BREAKS IN MEDITERRANIAN-CLIMATE ECOSYSTEMS

## Introduction

I proposed that extinction events and invasion events are related to the entrained, scale-specific structure of vertebrate communities, and tend to occur at scale breaks. Analysis of south Florida data confirms this, as does the analysis of biological invasions in mediterranean-climate ecosystems. The processes leading to extinction have been debated for many years. At a geologic time scale, the occurrence of large-scale extinction events has only recently been documented. Beyond the normal background of species turnover, the events of extinction and invasion documented and analyzed in this document also are punctuated. That is, they are beyond the normal background levels of both biological phenomenon. This is nothing new. That we are experiencing an extensive and intensive extinction event is well documented (e.g., Ehrlich and Ehrlich 1981, Raup 1991, Lawton and May 1995). That the cause of this event is direct human action also is well documented. Extinctions have been the focus of much research, and the loss of species has been bemoaned by many articulate biologists. I suggest that these events occur concomitantly with invasion, and that they are related not so much to human action *per se*, but to anthropogenic changes in structuring processes. The inhibition of

processes such as fire causes changes in ecological structure, leading to simultaneous events of invasion and extinction. Extinctions and invasions are mutually reinforcing. That is, the loss of species promotes the establishment of non-indigenous species, and invasions lead to the extinction of native species.

The analysis of invasive species is much more straight-forward than the analysis of declining species. Endangerment is usually unrecognized. The societal recognition of endangerment is largely based on political process. Also, the process of endangerment often is due to direct human action, such as pesticide poisoning and hunting. The process of listing a species as endangered often leads to the listing of large and charismatic species, both because these species are large and charismatic and because they often are better studied than small obscure species. Thus, a large fairly secure species may be listed, while an extremely rare and declining rodent species remains unacknowledged. The listing process also is flawed because it follows political rather than ecological boundaries. National listings may fail to recognize that a species is secure in many localities. State listings are highly political, and regardless of biological status the listed status of a species may vary across state boundaries. Therefore, much of the data on endangerment is suspect and strongly susceptible to errors of commission and omission. For those reasons I have concentrated on invasions rather than extinctions.

As suggested earlier, variability at scale breaks may not be limited to species turnover. In this chapter, I further test for patterns of species turnover and abundance in relationship to scale-specific vertebrate community structure by utilizing the mediterranean-climate faunas described in the previous chapter.

## Methods

### Data

Data relating to extinctions, rarity, and abundance were collected where available for mediterranean-climate ecosystems. Several sources providing species lists for those sites also provided data relevant to the questions raised in this chapter. Mammalian data sets from both southwestern and southcentral Australia (Strahan 1995) also provided data on extinction and rarity in the mammalian fauna. Farina (1997) provided a species list of Italian mediterranean-climate avifauna including species abundance. Status and population trend for those species were determined from Tucker and Heath (1994). These data were not used in the comparison of mediterranean-climate lump structure because the study area is much smaller in its spatial extent. The complete species list, lump structure, species abundance, status and trend may be found in Appendix G. The source for the San Diego county analysis of the previous chapter (Unitt 1984), also provided categorical abundance data. For both southwestern and southcentral Australia, Saunders and Ingram (1995), and Schodde (1981), respectively, categorized bird species as nomadic or sedentary.

All analyses were made in regard to scale specific community structure. Other hypotheses relating to decline and extinction in vertebrate communities were tested in Chapter 1. All data used in this chapter may be found in Appendix G.

Rare and declining species analysis

Analyses of southwestern and southcentral Australian avifaunas compared the distance to body mass lump edge between species listed as extinct, locally extinct and rare to species not categorized as such. For the Italian avifauna data, distance to body mass lump edge was compared between species with a declining trend or listed as vulnerable, threatened or rare (usually coinciding with a declining status) to "secure" species. Analysis of the San Diego county avifauna compared rare and extinct species to abundant, common, or uncommon species. Comparisons were made with the Mann-Whitney U test statistic (rank sum test) because the data was not normally distributed, variances were unequal, or both.

Analysis of abundance

The Italian bird data of Farina (1997) provided data on abundance. The abundance and variability in abundance of lump edge species was compared to the abundance and variability of intra-lump species. The Mann-Whitney U statistic compared the abundance of lump-edge species to other species in the distribution, and the Levene median test compared the variance in abundance between those two groups.

Analysis of nomadic birds

Analysis of nomadic birds was conducted in the same manner as analysis of invasive species in south Florida and mediterranean-climate systems. Nomads were removed from the species list, and occurrence of discontinuities was determined with monte carlo simulations as before. It was then determined whether the body mass of nomadic species placed them in body mass lumps, or at gaps in the distribution. As in

previous analysis, a species was conservatively considered to be an "edge" species only if its body mass placed it into a gap. Proximity to edge was not considered in this test, and chi-square analysis was used to determine the significance of pattern, if any.

## Results

### Rare and declining species

No significant difference could be detected in any of the data analyzed, although median values for the distance to body mass lump edge were smaller for declining, extinct, or rare species in all comparisons (Table 6-1). Statistical power for all tests was extremely low.

Table 6-1 Data set, comparison, n (N), median values (Median), probability level (P), and statistical power (Power) of comparisons of the distance to body mass lump edge between declining, listed, or extinct species and secure species. Statistical power is based on t-tests and thus overestimates the power achieved in the non-parametric tests reported.

| Data set | Comparison | N | Median | P | Power |
|---|---|---|---|---|---|
| Southwestern Australia | Extinct/rare | 18 | 0.065 | | |
| (mammals) | Secure | 24 | 0.092 | 0.22 | 0.10 |
| Southcentral Australia | Extinct/rare | 14 | 0.082 | | |
| (mammals) | Secure | 17 | 0.120 | 0.41 | 0.05 |
| Italy | Declining/ | | | | |
| (birds) | listed | 10 | 0.010 | | |
| | Secure | 46 | 0.014 | 0.32 | 0.05 |
| San Diego county | Rare/extinct | 24 | 0.024 | | |
| (birds) | Secure | 92 | 0.041 | 0.22 | 0.09 |

Analysis of abundance

The relative abundance (Farina 1997) of lump edge species was significantly less than the relative abundance of species not defining scale breaks. The median relative abundance of lump edge species was one-half the relative abundance of other species (Table 6-2). Mean values of relative abundance were 0.009 and 0.021, for edge and lump species, respectively. Variances were not significantly different between the two groups (Table 6-2).

Table 6-2. Relative abundance and associated variation in lump edge species as compared to species not defining the edge of lumps for birds in a central Italian study area. In the body of the table are listed the number of observations (N), the median relative abundance (Abundance), the probability level associated with abundance comparisons (Pa), the associated variance, and the probability level associated with variance comparisons (Pv).

| Group | N | Abundance | P(a) | Var | P(v) |
|---|---|---|---|---|---|
| Lump edge species | 16 | 0.004 | | 0.0001 | |
| Other species | 40 | 0.008 | 0.09 | 0.0011 | 0.154 |

Analysis of nomadic birds

The southwestern Australia bird list of Saunders and Ingram (1995) provided 122 species not classified as nomadic. Nineteen species were classified as nomadic. The list of Schodde (1981), for southcentral Australia, comprised 76 non-nomadic species and 48 bird species classified as nomadic. The structure of those communities and the discontinuity index associated with scale breaks may be found in Appendix G. The avifaunas of both systems were discontinuous.

Nomadic species tended to occur at scale breaks. Sixteen percent of southwestern Australia nomadic birds were associated with scale breaks, and 35% of

southcentral Australian nomadic birds. Observed numbers were considerably higher than expected values, especially in southcentral Australia (Table 6-3), and significant despite low degrees of freedom and statistical power.

Table 6-3. Association of nomadic bird species with scale breaks in Australian mediterranean-climate ecosystems. For each ecosystem (System) are listed the number of non-nomadic breeding species (Ns), the number of species listed as nomadic (Nn), expected number of species with body masses placing them in scale breaks (Exp), observed number of species occurring at scale breaks (Obs), the degrees of freedom associated with the chi-square test (DF) and the resulting probability value P.

| System | Ns | Nn | Exp | Obs | DF | P |
|---|---|---|---|---|---|---|
| Southwestern Australia | 122 | 19 | 1.86 | 3.00 | | |
| Southcentral Australia | 76 | 48 | 5.66 | 17.0 | 1 | 0.000001 |

## Discussion

The tests utilized in this chapter were unable to detect a significant association between endangerment and decline and proximity to scale breaks. The tests that originally suggested this association (Chapter 2) were not appropriate to the data available because of the large number of extinct and rare species (Australia) and the clumping of declining and rare species. Because of that, I resorted to tests of extremely low power. Median (and average) values for edge distance were lower for declining, extinct, and listed species in all cases, but probability levels were insignificant. Thus, the results of those tests were ambiguous and equivocal.

The analysis of the relative abundance of birds on an Italian mediterranean type study area demonstrated a relationship between scale breaks and lower abundance.

However, variability in abundance did not differ between species at scale breaks and species within a lump. Nomadic species in two widely separated mediterranean-climate ecosystems in southern Australia were associated with scale breaks.

Despite the inconclusive results relating rare, declining and extinct species to scale breaks, as a whole, the results of this chapter confirm earlier results. Lower abundance of Italian birds at scale breaks suggests lowered availability or perhaps greater spatial or temporal variability in resources at scale breaks. The occurrence of nomadic species at scale breaks suggests greater variability in resources at scale breaks, as does the relationship between body mass lump edges and seasonal southern migration in southern Florida birds (Chapter 4). Whether the resource or resources in question are related to food or space remains unknown. Species compete for a myriad of resources, not just the commonly investigated resource of food (Schoener 1982).

# CHAPTER 7
# VERTEBRATE COMMUNITY STRUCTURE WITHIN RANGES OF SCALE

## Introduction

Ecosystems are self-organizing; processes, species and ecological structure interact to reinforce and maintain the existing state of organization (Levin 1992). Ecological resilience refers to the amount of perturbation a system can incorporate before it reorganizes into a new state (Holling 1973). Peterson et al. (1998) provide a model that links biological diversity and resilience. This model differs from previous models in its incorporation of scale.

Slightly conflicting models of biological diversity and ecological resilience exist. The foremost two models are those of Ehrlich and Ehrlich (1981) and Walker (1992). Ehrlich and Ehrlich compared species in an ecosystem to the rivets of a plane. Many species (or rivets) can be lost before the system crashes. Explicit in that model is the idea of ecological (or functional) redundancy among species. The loss of some species can be tolerated as the loss is compensated for by species with redundant function. Walker's model (Walker 1992, 1995) extends the idea of keystone species (Paine 1969, Power et al. 1996) by suggesting that ecological function is maintained within a system by a small suite of "driver" species; all other species present are simply passengers with minor ecological roles. Both Ehrlich's and Walker's models imply that increasing species richness increases ecological resilience, and that functional redundancy is inherent in ecological systems.

Peterson et al. (1998) present an alternate model that incorporates scale into the relationship between species richness and ecological resilience. Their model proposed that species residing in a system are compartmentalized by scale. That is, they reiterated the model of Holling (1992) and directly related it to ecological resilience. Specifically, they hypothesized that species operating at the same range of scale are more likely to strongly interact (i.e., compete), especially if those species have the same ecological function or are from within the same guild. They hypothesized that these strong interactions within a range of scale would lead to a diversity of function within a scale because members of the same functional group or guild would tend to coexist only if they were able to operate at a different range of scale, where competition among them would be lessened. Thus, their model suggested that resilience was increased by maintaining maximal diversity within a range of scale and redundancy across ranges of scale. However, they noted that function that was apparently redundant was not, because functions were occurring at different scales (Figure 7-1). In addition to highlighting the effect of this within scale diversity and cross-scale redundancy on ecological resilience, the authors suggested that it would also reduce competition, whether or not the cause of the observed pattern was competition.

I tested an important component of the hypothesized model of Peterson et al. (1998) that is relevant to within and across-scale community assembly. Specifically, I was interested in whether I could detect pattern in vertebrate communities that could be attributed to competition. If, as Peterson et al. (1998) proposed, there is some element of competitive structuring to communities based on scale, this may explain some of the findings of earlier chapters.

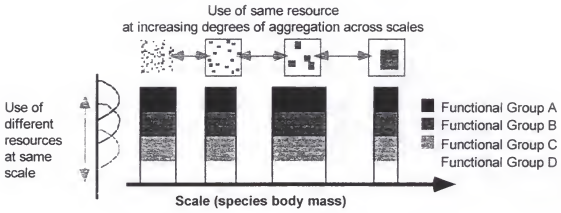


Figure 7-1. The relationship between scale-specific groupings of species and the distribution of function among species in an ecosystem. Within a single range of scale, functional diversity is maximized, but functional overlap adding to resilience exists. Across scales, there is redundancy of function, but the range of functional effectiveness varies. Modified from Peterson et al. (1998).

MacArthur proposed that science is a search for repeated pattern and for the explanation of those patterns (MacArthur 1972). Often, conclusions about assembly and process in communities have been based on the *a posteri* recognition of pattern. Hutchinson (1959) proposed that an observed minima of bill-size similarity ratio of 1:1.3 among coexisting species represented the results of competition and resulted in niche separation among otherwise similar species. Since Hutchinson, much research has seemingly supported the view that communities have been competitively structured (e.g., McNab 1971, Price 1972, Rosenzweig 1966, Schoener 1965). Wiens (1983), however, believed that the simple discovery of pattern was not a convincing argument for competition. Alternative hypotheses can be proposed to explain the pattern, though little effort is made to propose or test such alternatives. Simberloff and Boecklen (1981), suggested that the patterns that had been interpreted as indicative of competition could emerge by chance alone, and re-examined data presented to support non-random patterns among species. Using a conservative test that compared triplets

of species, Simberloff and Boecklen (1981) demonstrated that the conclusions of earlier tests were not robust when evaluated with their conservative statistics, and suggested that patterns often did not exist except by chance.

Potential problems do exist with research that has proposed competition as a structuring force of communities. Two problems are foremost. First, the level of analysis is often restricted. For example, patterns may be detected in narrowly defined guilds, or tests may be conducted at a restrictive taxonomic level, when competition, if it is important, is likely to involve whole suites of species of mixed taxa. For instance, the definition of a guild as heteromyid rodents (Bowers and Brown 1982) discounts the fact that other granivorous species (e.g., ants) may be competing for resources (Brown et al. 1979). Character displacement has been demonstrated for distantly related taxa. Although competition for resources may be strongest among taxonomically similar species (Darwin 1859)--such as groupings at the family level--competition may transcend arbitrary taxonomic cutoffs.

Intuition suggests that competition should be greatest among certain groups of species. Historically, hypotheses of competitive structuring of communities have been tested at the guild level. It is reasonable to expect that members of a guild are more likely to compete than random groupings of species. Unpublished data, and the model of Peterson et al. (1988) suggests that guild members are able to co-exist by exploiting resources at different environmental scales of space and time. Spread across scales may lead to a relatively even size spacing among members of the same guild. The model of Peterson et al. (1998) suggested that groups of species operating at the same scale may represent strongly competitive units. To test that hypothesis, I asked if species operating at the same range of scale (lump) were randomly distributed. Or, alternatively, is there an eveness of spacing (a measure of morphological over-dispersion; Moulton and Pimm 1986) present within lumps of species? The null hypothesis that species body masses within a lump were randomly distributed was

tested against the alternative hypothesis of a non-random distribution of species within a lump.

## Methods

### Sources of biological data

Mammal, bird, and herpetofauna (reptile and amphibian) data sets of body sizes were assembled for sites with reliable, comprehensive species lists. This includes the south Florida data used in earlier chapters, but also 29 other data sets provided by J. Sendzemir (Sendzemir *unpublished data*). Body mass values for birds and mammals were taken from a source most proximate to each study site, either from studies in the literature or from global compendia (Dunning, 1993; Silva and Downing, 1995). Sites were selected from six different biomes in the western hemisphere: boreal forest; temperate desert, forest, moist mid-grass prairie and seasonally wet prairie, and neotropical forest.

### Description of study sites

The 22 sites from which 33 animal data sets (Table 7-1) were assembled had sufficient size (study areas ranging from hundreds to thousands of hectares) and study history to provide reliable descriptions of the animal communities of these distinct systems over the past few decades. These study sites exhibited a broad range of landscape structure and climate-related parameters such as rainfall, temperature, and evapo-transpiration. The diversity and number of sites used provided a robust test of my hypothesis. These study sites are described in Sendzemir (1998); I provide a brief synopsis as follows.

Table 7-1. Study sites and data sets used to test for within-scale structuring in animal communities inhabiting a variety of ecosystems. Herps refers to reptiles and amphibians, Temp refers to temperate systems, and Neotrop refers to the neotropics. Numbers in the body of the table refer to species richness in each data set.

| Biome | Ecosystem | Site name | Birds | Mammals | Herps |
|---|---|---|---|---|---|
| Temp | Wet savanna | Everglades | 106 | 35 | 30 |
| | Forest | Itasca | 73 | 46 | -- |
| | Forest | Savannah River | 80 | 46 | -- |
| | Forest | Mnt Lake Biol. Sta. | 75 | -- | -- |
| | Prairie | Badlands | 26 | 28 | -- |
| | Prairie | Bison | 66 | 22 | -- |
| | Prairie | Cottonwood | 46 | -- | -- |
| | Prairie | Konza | 106 | 39 | -- |
| | Desert | Bryce | -- | 31 | -- |
| | Desert | Canyonlands | -- | 29 | -- |
| | Desert | Capital Reef | -- | 39 | -- |
| | Desert | Organ Pipe | -- | 28 | -- |
| | Desert | Zion | -- | 36 | -- |
| Boreal | Forest | Dore Lake | 129 | 42 | -- |
| | Forest | New Brunswick | 100 | 36 | -- |
| | Forest | Nopiming | 126 | 42 | -- |
| | Forest | Taiga Biol. Sta. | 84 | 43 | -- |
| Neotrop | Forest | Concepcion | -- | 39 | -- |
| | Forest | French Guiana | 112 | -- | -- |
| | Forest | La Selva | -- | 48 | -- |
| | Forest | Lacandona | -- | 46 | -- |
| | Forest | Manu | -- | 63 | -- |

Two landscape types characterized the Canadian boreal forest sites: continental (Dor Lake, Taiga Biological Station, Nopiming) and maritime (New Brunswick). The latter site, Green River in northwest New Brunswick, is an example of boreal forest with high topographic relief. The summits of high hills are sufficiently cold to support boreal forest in a mosaic of temperate-transitional Acadian forest. Habitat diversity is greater on the continental sites with a variety of bogs, thickets, and black spruce (*Picea mariana*) stands bordering many lakes.

Temperate forest sites were mixtures of conifers and hardwoods as well as coniferous/hardwood mixes, with wide temperature contrasts between Minnesota (Itasca State Park) and the eastern sites (The Mountain Lake Biological Station in Virginia, and the Savannah River Site in South Carolina). The Virginia site was a temperate northern hardwood site typical of poor, eroded soils in central Appalachia. Most of the forests were dominated by northern red oak (*Quercus rubra*) with scattered conifers. The site was a complex of ridges varying between 500 m and 1200 m in elevation. The Savannah River site had less topographic relief and variation. However, habitat types varied greatly with relatively small elevational change. Carolina bays and bottomland hardwoods dominated low areas, while mixed hardwood/pine forests dominate hillsides and pine stands dominated sandy ridges. Itasca state park exhibited the varied topography of compressed knob and kettle glacial landforms and included many lakes and forested wetlands. The park was dominated by second growth aspen (*Populus tremuloides*) and red (*Pinus resinosa*) and white pine (*Pinus strobus*), with maple/basswood (*Acer* sp., *Tilia americana*) forest invading areas of pineland.

The temperate prairie sites were mid-grass prairie (Badlands, Bison, Cottonwood) and tallgrass prairie (Konza). Prairie at the Badlands site was on the bottoms and sides of grassy valleys amid steep hills (< 200m). Streams were either open or bordered by dense juniper thickets. The Cottonwood site has a gently undulating landscape with less than 20 m in topographic relief. There were few trees at the Cottonwood site. The tallgrass site was high hills covered by grasses up to 2 m tall and dissected by streams with gallery forests. The temperate wet savanna/prairie was the Everglades sub-ecoregion in south Florida which was a mosaic of seasonally wet herbaceous marshes with scattered tree islands and wet pine flatwoods.

There were two types of desert: Coloradan (Bryce, Zion, Canyonlands, Capitol Reef) and Sonoran (Organ Pipe). The latter site is drier, with sparse shrubby

vegetation and cactus of various species, and more bare ground. The landscape is extensive undulating plains from which low mountains and buttes rise abruptly. Capitol Reef, Zion and Bryce Canyon National Park sites had much topographic variation with taller and more extensive forests (pinon-juniper, and fir). Canyonlands National Park is a maze of low, steep-sided desert canyons, with isolated pockets of ponderosa pine and Douglas fir.

Four neotropical rainforest (French Guiana, La Selva in Costa Rica, Selva Lacandona in Mexico, and Manu National Park in Peru) data sets were utilized. These four sites were typical of wet, multi-stratal evergreen forests. Manu National Park was in the largest area of undisturbed rainforest, and is richly structured. Additionally, Manu National Park has a varied topography, from flat riverine bottomland to bluffs to mountain foothills. Selva Lacandona in Chiapas, Mexico, had less topographic variety (predominately bottomlands) and more anthropogenic activity than Manu. The La Selva Biological Station in Costa Rica had considerable topographic variation (>100 m). The dominant vegetation type was primary forest on rolling terrain. There was more anthropogenic disturbance such as silviculture at La Selva. The French Guiana site was a large expanse of unbroken primary forest. The area of Concepcion in Bolivia has a relatively flat topography with some lowland hills and granitic domes (~ 700 m) and had a variety of forest types.

Statistical analysis

It was first necessary to determine the lump structure of vertebrates within each taxonomic group at each site by statistically detecting the discontinuities in the ranked body masses of species. This methodology was described in Chapter 2. The second step was to determine the variance associated with the line segment distance on a log10 body mass axis (i.e., log10n - (log10n +1)) between each species for each

individual lump of every data set. Third, observed variance in line segment lengths were compared with the output of 1000 simulations based on a null model.

Simulations with a null model

Analysis of within-lump segment lengths demonstrated that these distributions approximated a uniform distribution. Furthermore, for any given site it was impossible to ascertain the potential species pool for the entire community, but it was conservatively assumed that the size distribution approximated normal. For relatively small subsets, such as lumps, within that community size distribution, the most conservative neutral model against which to test observed distributions would be a uniform distribution. One-thousand simulations, with *n* and the range of log10 body masses identical to that of the observed lump, was created for each lump of species by drawing at random *n* times from a uniform distribution, which served as the null model for the species pool.

Two sources of bias in calculations of variance were removed from the statistical simulation model. Rounding error, such as excessive rounding and differences in the degree of rounding between observed and simulated log10 body mass data, was eliminated by rounding all data to three places prior to any calculations. Similarly, the potential for unreliable estimates of variance in lumps composed of few species (<5) was avoided by restricting the analysis to lumps with *n* greater than five. Since the body masses of the smallest and largest species in each lump were fixed during each simulation run, the species between the ends were the only body masses drawn at random. By restricting analysis to lumps with five or more species, the number of simulated body masses always exceeded the number held fixed.

Precautions were taken to simulate only the small scale segment length variance which exists within lumps. Segment length variance exists at the larger scale of the entire animal community and is generated by the major discontinuities or gaps

which separate lumps. This large-scale variance was removed during simulations by rejecting any segment lengths which exceeded the mean size of the gaps on either side of the simulated lump.

Within each lump the size spacing between species ("segment length" along the body mass axis) was calculated by subtracting the log10 body mass of the *n*th species from that of species n+1 . Evenness of spacing was quantified by examining the variance of segment lengths within the lump. Probabilities of observed variances occurring by chance were determined by comparing observed variances with the variance distributions generated from simulations of each lump. For each lump 1000 simulation runs generated a distribution of species within a lump, and variance for each repetition was calculated. The rank of the observed variance in that distribution of simulated variances approximated the p-value of the lump's segment length variance. Very low observed values would rank low in the simulated distribution, and be interpreted as a an eveness of spacing among species within a lump.

Meta-analysis

Difficulties inherent in field conditions can affect the precision of vertebrate body mass estimates. The discontinuities defining lumps of species in the vertebrate communities analyzed exceeded the normal variation inherent in species mass estimates (Sendzimir 1998). However, at the finer, within-lump scale, the sources of variation in size estimates due to sampling error make it less likely to find any constancy or evenness of spacing among body masses within a lump, especially at a significance level of $P < 0.05$.

Given the likelihood of minor sampling error, detecting significant trends in large quantities of data was accomplished with meta-analysis. Pattern at several scales - within taxa (i.e., birds and mammals), within biome, and overall (across all analyzed lumps) was examined using binomial tests (in addition to the absolute ranking

of observed within lump variance within the distribution of simulated variances). If observed variances occur at random, I would expect that the frequency distribution of variances to be normal with a mean at 0.5 (i.e., a ranking of 500 out of 1000 simulations). The observed variance in segment lengths could fall into one of two conditions with respect to the distribution of simulated variances: ranked above the 50 percent rank or below it With the expectation that random variance would generate near equal numbers of both conditions, the binomial test was applied. Significant numbers of occurrences below the 50 percent rank indicate greater evenness of spacing than expected by chance in the within taxa, biome, and overall tests.

Community-level simulations

To test if results were artifactual, and to further test if the body masses of species from within a system are discontinuously distributed, I ran the same series of simulations and procedures described above on the same 33 animal data sets in Table 7-1. That is, instead of applying simulations to data within lumps, the simulations were applied to the data without determining the lump structure. Because gaps were not a source of bias for this test, segment length in simulations was not forced below a maximal size. If observed variances were small compared to simulated variances, it would indicate morphological overdispersion at the community level. If variances were high, I would interpret this as indicative of discontinuities in the data.

## Results

Of the 170 lumps occurring in 32 data sets, 27 lumps were rejected by the criterion that required a minimum of five species within a lump for inclusion in my analysis. The following results are a summary of the observed variances of those 143 lumps as compared to 143*1000 simulations which established null distributions with which to compare observed values.

Simulated and observed trends in segment length variance

Observed segment length variances tended to be ranked in the lower half of variance distributions generated by simulation. This is evident (Figure 7-1) in the left-skew of the distribution of p-values for observed segment length variance. The normal distribution of variances expected from a uniform distribution of segment lengths highlights this trend. Seventeen percent (24 out of 143) of all lumps showed low variance of segment lengths ($P < 0.05$) when considering absolute rankings for comparing the observed variance with simulated variances for each lump separately.

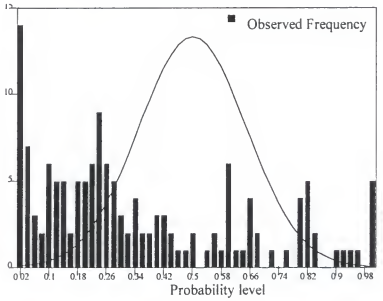


Figure 7-1. Histogram of probability levels (ranking in distribution of 1000 simulations) in observed variance of inter-species spacing in 143 mammal, bird and herpetofauna lumps. There is a left skew to the observed variance rankings. A random distribution of observed variances would generate a normal curve, solid line.

Binomial test for over-dispersion of segment lengths

Seventy-four percent of all lumps (106 of 143) from all sites had variances ranked in the lower half of the null distribution. The chance of such a majority occurring randomly is very small ($P < 2.19$ E-09) as indicated by the binomial test (Table 7-2). Similar majorities with highly significant probabilities (Table 7-2) occurred for binomial tests for each taxa (mammals, birds) and biome (temperate, boreal, neotropical). Mammal lump data sets exhibited the lowest variances. Note that mammals are more likely to be weighed in the field than birds, and a larger *n* is likely to lead to more precise body-mass estimates. Only half the bird lump data sets (boreal forest, temperate prairie) showed significantly low variance at the biome level. The sample of herpetofauna from South Florida is too small ($n = 6$) to reasonably expect a significant result with the binomial test. When the binomial test was applied to lump sums within each biome, a majority (6 out of 10) had significant p-values.

Table 7-2. Results of binomial tests comparing ranking of observed within lump variances with the distribution generated from 1000 simulations drawing from a unimodal null distribution of the same n and endpoints of each observed data set. Results are reported by taxa, biome, landcover type (Land) and across all data. The body of the table includes the observed number of data lumps falling below (<50) or above (>50) the 50% percentile of the simulated data sets and the mean ranking (Rank) of the observed data in either of the above two categories.

| Taxa | Biome | Land | <50 | Rank | >50 | Rank | Binomial Probability |
|---|---|---|---|---|---|---|---|
| Herps | Temperate | Wet | 4 | 21 | 2 | 59 | 0.234 |
| Mammals | Temperate | Desert | 17 | 17 | 2 | 77 | <0.001 |
| Mammals | Temperate | Forest | 7 | 19 | 3 | 63 | 0.117 |
| Mammals | Temperate | Prairie | 10 | 19 | 2 | 83 | 0.016 |
| Mammals | Boreal | Forest | 10 | 19 | 0 | -- | <0.001 |
| Mammals | Neotropical | Forest | 12 | 25 | 3 | 64 | 0.009 |
| Birds | Temperate | Forest | 16 | 21 | 11 | 76 | 0.097 |
| Birds | Temperate | Prairie | 8 | 11 | 2 | 65 | 0.044 |
| Birds | Boreal | Forest | 13 | 21 | 5 | 78 | 0.033 |
| Birds | Neotropical | Forest | 9 | 17 | 7 | 85 | 0.175 |

Table 7-2 cont.

| Taxa | Biome | Land | <50 | rank | >50 | rank | Binomial Probability |
|---|---|---|---|---|---|---|---|
| All temperate sites | | | 62 | 18 | 22 | 70 | <0.001 |
| All boreal sites | | | 23 | 20 | 5 | 78 | <0.001 |
| All neotropical sites | | | 21 | 21 | 10 | 75 | 0.021 |
| All mammals | | | 56 | 29 | 10 | 70 | <0.001 |
| Al birds | | | 46 | 18 | 25 | 73 | 0.004 |
| All data combined | | | 106 | 19 | 37 | 74 | <0.001 |

Tests for potential bias or artifact

If within lump *n* and P-level (ranking of observed variance) were correlated, some of our results may have been artifactual. However, no correlation between within lump *n* and ranking of variance was evident (Figure 7-2). If species' body masses clustered within lumps, segment length variance could still be significantly low. No clustering is evident within a lump. Regression of normalized segment length on normalized relative position within the lump shows no significant trend either for all taxa (Figure 7-3) or for mammals or birds separately.

Community-level simulations

When the same data were analyzed at a community level, the observed segment length variance tended to be ranked in the upper half of the null distributions. Twelve of 13 bird and 9 of 20 mammal data sets had variances in the upper half of the null distributions (64%). Thirteen of 33 data sets had variances that ranked in the upper 5% of the null distributions (39%). A binomial test revealed that there were significantly more ($P = 0.041$) variances ranked in the upper half of their respective null distributions across all 33 data sets.

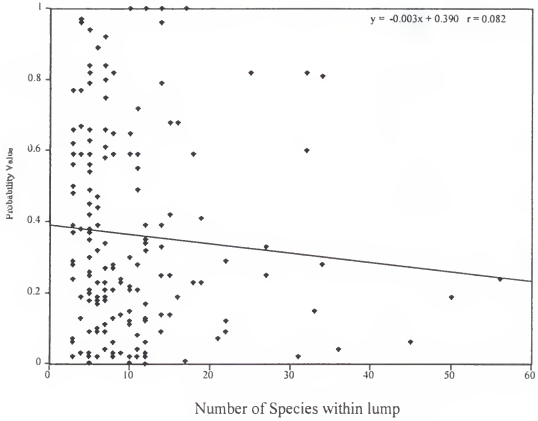


Figure 7-2. Correlation between within lump n and ranking of observed variance within the distribution of simulated variances.

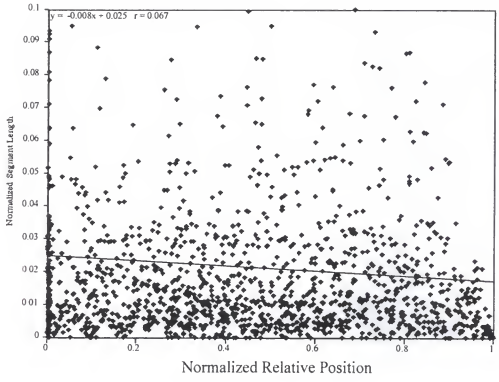


Figure 7-3. Regression of normalized segment length with normalized relative position within a body-mass lump.

## Discussion

The results indicate that inter-species spacing within lumps was more constant than random. Species within a lump were not randomly distributed, or clumped. Even accepting only those lumps where $P < 0.05$, a large number exhibited very low variances compared to the output from computer simulations. The results of higher than expected variance of segment lengths for entire animal communities suggests clumped data at the community level. This reinforces the hypothesis that vertebrate body mass distributions from within a system are discontinuous.

These data support the hypotheses and model of Peterson et al. (1998). If morphological overdispersion is a measure of competition within communities, my data demonstrates that a competitive signature is present. This signature is present only in groups of species which operate at the same range of scale, but not at the community level. Previous findings suggesting morphological overdispersion and community structuring due to competition have also tended to segregate communities into groupings, either ecologically similar species or taxonomically related species.

The role of competition in community structure was accepted in the early years of community ecology, and was a central focus in ecology. In the late 1970s and early 1980s the role of competition was questioned (Simberloff and Boecklen 1981). More recently, community ecology has again focused on the role of competition in structuring communities. The role of competition in shaping communities of introduced birds has received considerable attention. Communities of introduced species in anthropogenic habitats are shaped by competition, and competitive assembly affects introduction success.

My results may be interpreted as supporting a competition hypothesis. Others have thoroughly explored the shortcomings of investigations of pattern that have concluded that communities were shaped by competition. I believe I have addressed

the major shortcomings of pattern investigation--*a posteri* conclusions, small samples, and the lack of a null model. I believe that many other studies have demonstrated the role of competition in the structuring of communities. Moulton and colleagues have demonstrated non-random pattern in several introduced bird communities (e.g., Moulton 1985, Moulton and Pimm 1986, Moulton and Lockwood 1992). The use of introduced bird communities has two advantages. First, evolutionary forces likely can be discounted in communities that have formed in the past 100 years. Second, in these communities we know not only which species have survived but also which have failed. In these analyses the pattern of morphological overdispersion likely due to competitive interactions has been repeatedly shown. In these analyses, the first principal component invariably reflects the overall body sizes of the species (Moulton and Pimm 1986). Bowers and Brown (1983) documented limiting similarity among coexisting granivorous rodents at a local level. When they conducted the same tests on combined guilds of desert rodents, they were unable to detect limiting similarity among species. The rejection of the null hypothesis in our tests substantiates the model of Holling (1992), including the natural grouping of species (lumps) based on the scale of environmental exploitation.

My results also suggest competitive structuring in communities. However, the communities I tested had no taxonomic or ecological limitations and were constrained only by the spatial limitations of the inhabited system and scalar divisions among species. The recognition of a hierarchically scaled framework for ecological communities is not new (O'Neill et al. 1986), nor is it a new concept in other fields (e.g., the human body has long been recognized as a hierarchically organized system). However, hierarchical organization in ecological communities has remained largely in the theoretical realm in ecology. These findings differ from others suggesting a component of competition in community structure in that the segregation is one of scale, rather than some taxonomic division. They suggest that in addition to the

expected variability at scale breaks, competitive structuring within lumps may provide a degree of invasion resistance for species whose body masses place them in the interior of body mass lumps. My results strongly support the model of hierarchically scaled organization in ecological systems and suggest that competition shapes within and cross-scale community organization and assembly.

# CHAPTER 8
# CONCLUSIONS AND SYNTHESIS: A HIERARCHICAL MODEL OF COMMUNITY ASSEMBLY

## Introduction

Building upon the findings in this document, the hypothesis of Holling (1992), the model of Peterson et al. (1998), and discussions with many, I offer a model of community assembly that incorporates scale and recognizes that landscapes differ in the opportunity they offer animals. I propose that community assembly rules fall into three categories nested from coarse to small scales. First, lumpy landscape patterns set a template for the coarse level of community organization. Species attributes become tuned to or entrained by the landscape template, due to the different patterns on the landscape at different scales, into distinct body-mass behavioral categories. The categories are distinct because the available landscape patterns are not continuous, they are discontinuous with identifiable scale breaks separating them. Second, species representing feeding guilds are spread among body mass lumps (Peterson et al. 1998), with the consequence that competition for food is reduced, whether or not that is the proximate cause. The third and finest set of rules structuring communities occurs among species within a single body mass lump category. Within a single scale range, food competition is minimal because other members of their feeding guild are in other body mass lumps. But there is competition for other resources (Chapter 7), defined by place and texture, that are all at the same range of scales exploited all by members of

that lump, irrespective of what they eat. The model is expanded upon below, as is evidence for the form of these rules. The first level in this hierarchical model was forwarded by Holling (1992).

Rules imposed by the landscape template

There is growing evidence from nature, models and theory that ecosystem structure and dynamics are dominated by the influence of a small set of plant, animal, and abiotic processes (Carpenter and Leavitt 1991, Holling 1986, Holling 1992, Levin 1992). Each set of processes operates at characteristic periodicities and spatial scales (Holling, 1992). Small and fast scales are dominated by biophysical processes that control plant morphology and function. At a larger and slower scale of patch dynamics, interspecific plant competition for nutrients, light and water, interacting with climate, affects local species composition and regeneration. At a still larger scale of stands in a forest or grassland, meso-scale processes of fire, storm, insect outbreak and large mammal herbivory determine structure and successional dynamics from tens of meters to kilometers and years to decades. Still larger landscape scales have geomorphological and evolutionary processes that affect structure and dynamics over hundreds of kilometers and millennia. These processes produce patterns and are reinforced by those patterns. In short, they are self-organizing.

Holling (1992) argued that those temporal and geometric patterns of vegetation cause, or more specifically, entrain, patterns in morphological and behavioral attributes of the associated communities of animal species. The lumpy vegetation/landscape structures establish a non-random template with which animals

interact. Holling proposed that animal adaptation, dispersal and survival have led to communities that are entrained by this lumpy, hierarchical landscape structure and the scale-specific pattern present at each scale. Animal morphologies are entrained by landscape pattern such that clusters of animal sizes correspond to particular scale ranges over which structuring processes operate. Over time, certain animal size ranges would be more adaptive over specific scale ranges.

Holling (1992) demonstrated the lumpy (multi-modal) distribution of body masses in mammal and bird communities in boreal biomes. Lumps of species are groupings of species based on body mass. Species within a lump perceive and operate in and perceiving the environment at the same range of scale, and are characteristically separated by distinct and detectable gaps (see Figures, Chapter 2).

It has now been demonstrated that lumpy distributions of body mass also occur in herpetofauna, pre-historic mammal assemblages (Lambert and Holling 1998), and bird and mammal communities from all landscapes investigated (Meisel 1995, Restrepo et al. 1997, Sendzemir 1998, this document). However, lumpy body mass distributions are not clearly evident for pelagic birds (Holling 1992).

Rules partitioning species within feeding guilds

Species in feeding guilds are spread among several body mass lumps. For example, the 35 species of avian predators of budworm are spread among five body mass lumps (Holling 1988). These birds are part of the keystone process by which budworm produces and maintains pattern in the fir/spruce forest. The birds influence the process by keeping budworm populations low when trees are small, and allowing

release of an outbreak when tree ages are over 40 years. The birds are critical in making budworm a meso-scale producer of landscape patterns.

Having the birds in several lump size categories adds great robustness to their role and hence resilience to the pattern produced. That comes not because the functional forms of their predation are identical (redundant), but because they have overlapping ranges of effectiveness, spreading the impact over a wide range of budworm densities and wide ranges of spatial aggregation. For example, the little kinglets, chicadees and warblers concentrate on recognizing opportunity at the scale of needles or small tufts of needles. In contrast, the large evening grosbeaks react to stand level concentrations of food, for example explosions of seeds in a good mast year or of budworm in a stand-level outbreak. Hence species of each lump concentrate on different levels of aggregation of foods; on branches, or on whole trees, or in stands or in groups of stands, depending whether they are in small or larger lump categories. Their numerical responses are similarly aggregated, i.e., that part of the response that is associated with dispersal. Species in each lump of ascending size are drawn in from a progressively wider area as local hot spots of resource concentration develop.

## Rules for morphological overdispersion

The third level in the hierarchical structuring of communities involves species exploiting resources at the same scale, and was the focus of Chapter 7. Despite the difficulties inherent with univariate field-generated data, that is the variation inherent in my data sets of vertebrate body masses, I rejected the null hypothesis of random

distribution of body masses within groups (lumps) of species utilizing the environment at the same spatio-temporal scale.

## A hierarchical model

I have asked, if hierarchical landscape structure sorts animal communities into groups which each exploit the environment at a specific scale, what processes affect community structure within these lumps? I suggest that entrainment, displacement, assortment, and competition all structure communities, with their domain of influence each constrained by scale.

I suggest that communities are hierarchically structured (Figure 8-1). The structure of a landscape is due to the actions of a few key processes. Differences in the temporal-spatial scale of key processes creates a hierarchically structured landscape. Animal communities are grossly structured by the landscape. Scale-specific pattern in the landscape caused by the actions of processes acting at distinct temporal-spatial scales entrain vertebrate body masses such that discrete lumps (i.e., grouping of species that perceive and exploit the environment at the same range of scale) occur within vertebrate communities. Lumps of species exploit their environment at a distinct spatio-temporal scale. Species in different lumps exploit their environment at a different scale. Species that tend to be the most similar ecologically, phylogenetically, and morphologically, that is, species within the same guild, tend to co-exist by occupying different lumps, that is, by exploiting their environment at a different spatio-temporal scale than other members of the same guild or functional group. I interpret this as a competitive effect.

Species operating at the same scale, lumps of species in the terminology of Holling (1992), are shaped by competition. Resources available at a given spatio-temporal scale are limited, and competition for these resources leads to a relatively even spacing of species within a lump. Species within a single lump are unlikely to share many basic characteristics other than the scale at which they exploit their environment. Competition within a lump may be for food, shelter, nesting sites, predator free sites, or simply space. Competition for space may be especially intense (Schoener 1982). I do not wish to speculate on the exact resource being competed for; most likely competition varies in space and time and spans a wide range of resources.

I suggest that the structure of communities is based on hierarchical processes each acting at different scales. I have outlined above how I envision the structuring of vertebrate communities to be a hierarchically ordered process. However, the structure of communities is multi-causal, and I have dealt only with what I believe to be a significant influence. Taxonomy, phylogeny, trophic interactions, and other forces help shape a given fauna. But, are ecological communities exclusive associations of closely interdependent and co-evolving species, or just a haphazard sample of species inhabiting a region that happen to jointly tolerate the environment of the moment, as Jackson (1994) asks? I suggest that neither and both are true, depending on the scale of analysis. Ecological communities are adjusted (entrained) to a scale of structure

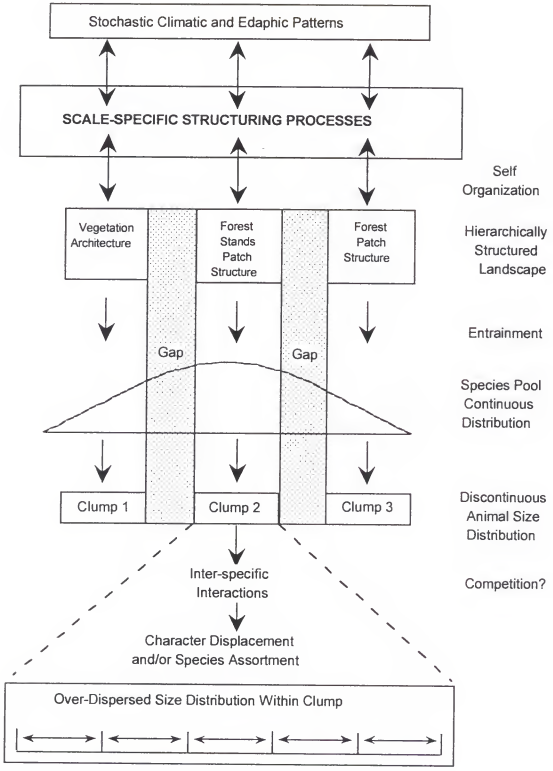


Figure 8-1. A hierarchical model of community assembly.

within the environment and within each domain of scale species compete with other species exploiting the environment at the same range of scales.

## Invasions and extinctions

The impact of biological invasions and extinctions is greater than the simple loss or addition of individual species. Where functionally important species are lost, ecological systems may collapse (Bond and Slingsby 1984). When especially aggressive non-indigenous species are introduced, the effects may be far reaching and unexpected (Savidge 1987). However, most hypotheses regarding extinction-prone or invasive species are only narrowly applicable and, unless so vague as to be meaningless (e.g., disturbance), have no predictive power. I suggest that both phenomena are at least partially understandable by understanding the link between the ecological structure unique to ecosystems and landscapes and the scale specific opportunities provided by a given ecological structure.

When the processes that structure ecosystems are perturbed, the resulting changes in ecological structure are expected to affect the entrained vertebrate community. Perturbation affects the course scale of community assembly, but effects are seen at all levels, including the fine scale, i.e., in the lump and gap architecture of the vertebrate communities. Invasions and extinctions are the expected result of changes in structuring processes. When a single process structuring a limited scale range is perturbed, loss of entire lumps of species is the expected results (Morton 1990). I have documented variability in both species composition and populations at scale breaks in transforming landscapes, in a large number of systems. However,

increased variability at scale breaks is likely to be a phenomena present in relatively unperturbed systems as well. Increased variability is expected at scale breaks under all conditions (Wiens 1989).

# APPENDIX A
# DIET, FORAGING STRATA, AND BODY MASS OF VERTEBRATE SPECIES IN SOUTH FLORIDA

| Common Name | Latin Name | Mass (g)[1] | Class | Diet | Strata |
|---|---|---|---|---|---|
| **Avifauna** | | | | | |
| Ruby-throated Hummingbird | *Archilochus colubris* | 3.15 | Native | | |
| Blue-gray Knatcatcher | *Polioptila caerulea* | 6 | Native | | |
| Prairie Warbler | *Dendroica discolor* | 7.65 | Native | | |
| Northern Parula | *Parula americana* | 8.6 | Native | | |
| Yellow-throated Warbler | *Dendroica dominica* | 9.4 | Native | | |
| Yellow Warbler | *Dendroica petechia* | 9.5 | Native | | |
| Common Yellowthroat | *Geothlypis trichas* | 10.1 | Native | | |
| Brown-headed Nuthatch | *Sitta pusilla* | 10.2 | Native | | |
| White-eyed Vireo | *Vireo griseus* | 11.4 | Native | | |
| Pine Warbler | *Dendroica pinus* | 11.9 | Native | | |
| Prothonotary Warbler | *Protonotaria citrea* | 14.3 | Native | | |
| N Rough-winged Swallow | *Stelgidopteryx serripennis* | 15.9 | Native | | |
| Barn Swallow | *Hirundo rustica* | 16 | Native | | |
| Red-eyed Vireo | *Vireo olivaceus* | 16.7 | Native | | |
| Grasshopper Sparrow | *Ammodramus savannarum* | 17 | Native-E | Carnivore | Ground |
| Black-whiskered Vireo | *Vireo altiloquus* | 17.9 | Native | | |
| Carolina Wren | *Thryothorus ludovicianus* | 18.7 | Native | | |
| Bachman's Sparrow | *Aimophilia aestivalis* | 20.2 | Native-E | Herbivore | Ground |
| Cave Swallow | *Hirundo fulva* | 20.4 | Exotic | Carnivore | Arboreal |
| House Finch | *Carpodacus mexicanus* | 21.4 | Exotic | Herbivore | Ground |
| Tufted Titmouse | *Parus bicolor* | 21.6 | Native | | |
| Seaside Sparrow | *Ammodramus maritimus* | 23.25 | Native-E | Carnivore | Ground |
| Chimney Swift | *Chaetura pelagica* | 23.6 | Native | | |
| Downy Woodpecker | *Picoides pubescens* | 27 | Native | | |

| | | | | | |
|---|---|---|---|---|---|
| Red-whiskered Bulbul | *Pyconotus jocosus* | 27.4 | Exotic | Herbivore | Fossorial |
| House Sparrow | *Passer domesticus* | 27.7 | Exotic | Herbivore | Ground |
| Summer Tanager | *Piranga rubra* | 28.2 | Native | | |
| Budgerigar | *Melopsittacus undulatus* | 29 | Exotic | Herbivore | Ground |
| Common Ground-Dove | *Columbigallina passerina* | 30.1 | Native | | |
| Eastern Bluebird | *Sialia sialis* | 31.6 | Native | | |
| Great Crested Flycathcer | *Myiarchus crinitus* | 33.5 | Native | | |
| Shiny Cowbird | *Molothrus bonariensis* | 35.3 | Exotic | Herbivore | Ground |
| Rufous-sided Towhee | *Pipilo erythrophthalmus* | 40.5 | Native | | |
| Red-crested Cardinal | *Paroaria coronata* | 43 | Exotic | Herbivore | Ground |
| Eastern Kingbird | *Tyrannus tyrannus* | 43.6 | Native | | |
| Red-cockaded Woodpecker | *Picoides borealis* | 43.6 | Native-E | Carnivore | Fossorial |
| Gray Kingbird | *Tyrannus dominicensis* | 43.8 | Native | | |
| Brown-headed Cowbird | *Molothrus ater* | 43.9 | Exotic | Carnivore | Ground |
| Spot-breasted Oriole | *Icterus pectoralis* | 44.5 | Exotic | Herbivore | Fossorial |
| Northern Cardinal | *Cardinalis cardinalis* | 44.65 | Native | | |
| Loggerhead Shrike | *Lanius ludovicianus* | 47.4 | Native-E | Carnivore | Arboreal |
| Northern Mockingbird | *mimus polyglottos* | 48.5 | Native | | |
| Puple Martin | *Progne subis* | 49.4 | Native | | |
| Red-winged Blackbird | *Agelaius phoeniceus* | 52.55 | Native | | |
| Canary-winged Parakeet | *Brotogeris versicoluras* | 60.4 | Exotic | Herbivore | Fossorial |
| Common Nighthawk | *Chordeiles minor* | 61.5 | Native | | |
| Red-bellied Woodpecker | *Melanerpes carolinus* | 61.7 | Native | | |
| Mangrove Cuckoo | *Coccyzus minor* | 63.9 | Native | | |
| Yellow-billed Cuckoo | *Coccyzus americanus* | 64 | Native | | |
| Hairy Woodpecker | *Picoides villosus* | 66.25 | Native | | |
| Brown Thrasher | *Toxostoma rufum* | 68.8 | Native | | |
| Red-headed Woodpecker | *Melanerpes erythrocephalus* | 71.6 | Native | | |

| | | | | | |
|---|---|---|---|---|---|
| Scrub Jay | *Aphelocoma coerulescens* | 80.2 | Native-E | Omnivore | Ground |
| European Starling | *Sturnus vulgaris* | 82.3 | Exotic | Carnivore | Ground |
| Least Bittern | *Ixobrychus exilis* | 86.3 | Native | | |
| Blue Jay | *Cyanocitta cristata* | 86.8 | Native | | |
| Eastern Meadowlark | *Sturnella magna* | 89 | Native | | |
| Killdeer | *Charadrius vociferus* | 96.55 | Native | | |
| Monk Parakeet | *Myiopsitta monachus* | 101 | Exotic | Herbivore | Fossorial |
| Smooth-billed Ani | *Crotophaga ani* | 105 | Exotic | Carnivore | Ground |
| Dusky-headed Parakeet | *Aratinga weddellii* | 108 | Exotic | Herbivore | Fossorial |
| Carolina Parakeet | *Conuropsis carolinensis* | 109 | Native-E | Herbivore | Fossorial |
| Common Myna | *Acridotheres tristis* | 110 | Exotic | Omnivore | Ground |
| Common Grackle | *Quiscalus quiscula* | 113.5 | Native | | |
| American Kestrel | *Falco sparverius* | 115.5 | Native-E | Carnivore | Arboreal |
| Mourning Dove | *Zenaida macroura* | 119 | Native | | |
| Chuck-will's-widow | *Caprimulgus carolinensis* | 120 | Native | | |
| Rose-ringed Parakeet | *Psittacula krameria* | 127.5 | Exotic | Herbivore | Fossorial |
| Black-hooded Parakeet | *Nandaynus nenday* | 128 | Exotic | Herbivore | Fossorial |
| Northern Flicker | *Colaptes auratus* | 132 | Native | | |
| Ringed Turtle-Dove | *Streptopelia risoria* | 136 | Exotic | Herbivore | Ground |
| Belted Kingfisher | *Ceryle alcyon* | 148 | Native | | |
| Eurasian Collared-Dove | *Streplopelia decaoto* | 149 | Exotic | Herbivore | Ground |
| White-winged Dove | *Zenaida asiatica* | 153 | Exotic | Herbivore | Ground |
| Burrowing Owl | *Speotyto (Athene) cunicularia* | 155 | Native | | |
| Blue-crowned Parakeet | *Aratinga acuticaudata* | 165 | Exotic | Herbivore | Fossorial |
| Black-necked Stilt | *Himantopus mexicanus* | 166 | Native | | |
| Boat-tailed Grackel | *Quiscalus major* | 166.5 | Native | | |
| Northern Bobwhite | *Colinus virginianus* | 178 | Native | | |
| Eastern Screech-Owl | *Otus asio* | 180.5 | Native | | |

| | | | | | |
|---|---|---|---|---|---|
| Hill Myna | *Gracula religiosa* | 192 | Exotic | Herbivore | Fossorial |
| American Woodcock | *Scolopax minor* | 197.5 | Native | | |
| Red-masked Parakeet | *Aratinga erythrogenys* | 200 | Exotic | Herbivore | Fossorial |
| Mitred Parakeet | *Aratinga mitrata* | 200 | Exotic | Herbivore | Fossorial |
| Purple Gallinule | *Porphyrula martinica* | 210 | Native | | |
| Green Heron | *Butorides virescens* | 212 | Native | | |
| Willet | *Catoptrophorus semipalmatus* | 215 | Native | | |
| White-crowned Pigeon | *Columba leucocphala* | 247 | Native-E | Herbivore | Fossorial |
| Fish Crow | *Corvus ossifragus* | 285 | Native | | |
| Pileated Woodpecker | *Dryocopus pileatus* | 287 | Native | | |
| Red-crowned Parrot | *Amazona viridigensalis* | 294 | Exotic | Herbivore | Fossorial |
| Clapper Rail | *Rallus longirostris* | 297 | Native | | |
| Common Moorhen | *Gallinula chloropus* | 302.5 | Native | | |
| White-tailed Kite | *Elanus leucurus* | 333 | Native | | |
| Orange-winged Parrot | *Amazona amazonica* | 338 | Exotic | Herbivore | Fossorial |
| Cattle Egret | *Bubulcus ibis* | 338 | Exotic | Carnivore | Ground |
| Little Blue Heron | *Florida caerulea* | 339.5 | Native-E | Carnivore | Water |
| Chestnut-fronted Macaw | *Ara severa* | 347 | Exotic | Herbivore | Fossorial |
| Rock Dove | *Columba livia* | 354.5 | Exotic | Herbivore | Ground |
| King Rail | *Rallus elegans* | 360.5 | Native | | |
| Snowy Egret | *Egretta thula* | 371 | Native-E | Carnivore | Water |
| Tricolored Heron | *Egretta tricolor* | 374.5 | Native-E | Carnivore | Water |
| Snail Kite | *Rostrhamus sociabilis* | 378 | Native-E | Carnivore | Arboreal |
| Pied-bill Grebe | *Podilymbus podiceps* | 442 | Native | | |
| American Swallow-tailed Kite | *Elanoides forficatus* | 442 | Native | | |
| American Crow | *Corvus brachyrhynchos* | 448 | Native | | |
| Reddish Egret | *Egretta rufescens* | 450 | Native-E | Carnivore | Water |
| Black Francolin | *Francolinus francolinus* | 453 | Exotic | Herbivore | Ground |

| | | | | | |
|---|---|---|---|---|---|
| Short-tailed Hawk | *Buteo brachyurus* | 495 | Native | | |
| Yellow-headed Parrot | *Amazona oratrix* | 500 | Exotic | Herbivore | Fossorial |
| Ivory-billed Woodpecker | *Campephilus principalis* | 511 | Native-E | Carnivore | Fossorial |
| Barn Owl | *Tyto alba* | 523.5 | Native | | |
| Red-shouldered Hawk | *Buteo lineatus* | 559 | Native | | |
| Hooded Merganser | *Lophodytes cucullatus* | 610 | Native | | |
| Glossy Ibis | *Plegadis falcinellus* | 633.75 | Native | | |
| American Coot | *Fulica americana* | 642 | Native | | |
| Yellow-crowned Night-Heron | *Nyctanassa violacea* | 682.5 | Native | | |
| American Bittern | *Botaurus lentiginosus* | 706 | Native | | |
| Fulvous Whisting-Duck | *Dendrocygna biocolor* | 710 | Exotic | Herbivore | Water |
| Barred Owl | *Strix varia* | 716.5 | Native | | |
| Black-bellied Whistling Duck | *Dendrocygna autumnalis* | 831 | Exotic | Herbivore | Water |
| Great Egret | *Casmerodius albus* | 873.5 | Native | | |
| Black-crowned Night-Heron | *Nycticorax nycticorax* | 883 | Native | | |
| Crested Caracara | *Caracara (Polyborus) plancus* | 893.5 | Native-E | Carnivore | Ground |
| White Ibis | *Eudocimus albus* | 900 | Native | | |
| Mottled Duck | *Anas fulvigula* | 999 | Native | | |
| Great Horned Owl | *Bubo virginianus* | 1028 | Native | | |
| Limpkin | *Aramus guarauna* | 1080 | Native-E | Carnivore | Water |
| Mallard | *Anas platyrhynchos* | 1082 | Exotic | Carnivore | Water |
| Red-tailed Hawk | *Buteo jamaicensis* | 1126 | Native | | |
| Turkey Vulture | *Cathartes aura* | 1467 | Native | | |
| Osprey | *Pandion haliaetus* | 1485.5 | Native | | |
| Roseate Spoonbill | *Ajaia ajaja* | 1522.5 | Native-E | Carnivore | Water |
| Double-crested Cormorant | *Phalacrocorax auritus* | 1674 | Native | | |
| Black Vulture | *Coragyps atratus* | 2080.5 | Native | | |
| Wood Stork | *Mycteria ameriana* | 2376 | Native-E | Carnivore | Water |

| | | | | | |
|---|---|---|---|---|---|
| Great Blue Heron | *Ardea herodias* | 2390 | Native | | |
| Muscovy duck | *Cairina moschata* | 2468.5 | Exotic | Herbivore | Water |
| Canada Goose | *Branta canadensis* | 3564 | Exotic | Herbivore | Water |
| Common Peafowl | *Pavo cristatus* | 4187.5 | Exotic | Herbivore | Ground |
| Bald Eagle | *Haliaeetus leucocephalus* | 4740 | Native-E | Carnivore | Arboreal |
| Sandhill Crane | *Grus canadensis* | 5089 | Native-E | Omnivore | Water |
| Wild Turkey | *Meleagris gallopavo* | 5811 | Native | | |

**Herpetofauna**

| | | | | | |
|---|---|---|---|---|---|
| Little grass frog | *Pseudacris ocularis* | 0.21 | Native | | |
| Squirrel treefrog | *Hyla squirella* | 0.37 | Native | | |
| Florida cricket frog | *Acris gryllus* | 0.49 | Native | | |
| Greenhouse frog | *Eleutherodactylus planirostris* | 0.6 | Exotic | Carnivore | Ground |
| Dwarf salamander | *Eurycea quadridigita* | 0.67 | Native | | |
| Florida chorus frog | *Pseudacris nigrita* | 0.75 | Native | | |
| Reef gecko | *Sphaerodactylus notatus* | 0.75 | Exotic | Carnivore | Arboreal |
| Ground skink | *Scincella laterale* | 0.9 | Native | | |
| Brahminy blind snake | *Ramphotyphlops braminus* | 0.92 | Exotic | Carnivore | Fossorial |
| Oscellated gecko | *Sphaerodactylus argus* | 0.98 | Exotic | Carnivore | Arboreal |
| Ashy gecko | *Spaerodactylus elegans* | 1.28 | Exotic | Carnivore | Arboreal |
| Mole skink | *Eumeces egregius* | 1.3 | Native-E | Carnivore | Ground |
| Rim rock crowned snake | *Tantilla oolitica* | 1.34 | Native-E | Carnivore | Fossorial |
| Oak toad | *Bufo quercicus* | 1.38 | Native | | |
| E narrow-mouthed toad | *Gastrophryne carolinensis* | 1.5 | Native | | |
| Spring peeper | *Hyla crucifer* | 1.78 | Native | | |
| Crowned snake | *Tantilla relicta* | 1.9 | Native | | |
| Yellowhead gecko | *Gonatodes albogulari* | 1.95 | Exotic | Carnivore | Arboreal |

| | | | | | |
|---|---|---|---|---|---|
| Green anole | *Anolis carolinensis* | 2.2 | Native | | |
| Bark anole | *Anolis distichus* | 2.66 | Native | | |
| Pine woods treefrog | *Hyla femoralis* | 2.74 | Native | | |
| Indo-pacific gecko | *Hemidactylus garnoti* | 2.76 | Exotic | Carnivore | Arboreal |
| Ringnecked snake | *Diadophis punctatus* | 2.96 | Native | | |
| Mediterrean gecko | *Hemidactylis turcicus* | 3.44 | Exotic | Carnivore | Arboreal |
| Southern leopard frog | *Rana sphenocephala* | 3.52 | Native | | |
| Florida scrub lizard | *Seloperus woodi* | 4.1 | Native-E | Carnivore | Ground |
| Green treefrog | *Hyla cinerea* | 5 | Native | | |
| Brown snake | *Storeria dekayi* | 5 | Native | | |
| Brown anole | *Anolis sagrei* | 5.18 | Exotic | Carnivore | Ground |
| Peurtoa Rican coqui | *Eleutherodactylus coqui* | 5.28 | Exotic | Carnivore | Ground |
| Mud snake | *Farancia abacura* | 6.27 | Native | | |
| Six-lined racerunner | *Cnemidophorus sexlineatus* | 8 | Native | | |
| Scarlet snake | *Cemophora coccinea* | 8.73 | Native | | |
| Crested anole | *Anolis cristatellus* | 8.99 | Exotic | Omnivore | Arboreal |
| SE five-Lined skink | *Eumeces inexpectatus* | 10.6 | Native | | |
| Southern toad | *Bufo terrestris* | 11.1 | Native | | |
| Ribbon snake | *Thamnophis sauritus* | 11.2 | Native | | |
| Pig frog | *Rana grylio* | 11.99 | Native | | |
| Rainbow whiptail | *Cnemidophorus lemniscatus* | 13.1 | Exotic | Carnivore | Ground |
| Garter snake | *Thamnophis sirtalis* | 15.65 | Native | | |
| Barking treefrog | *Hyla gratiosa* | 15.82 | Native | | |
| Rough green snake | *Opheodrys aestivus* | 19 | Native | | |
| Cuban treefrog | *Osteopilus septentrionalis* | 20 | Exotic | Carnivore | Arboreal |
| Pigmy rattlesnake | *Sistrurus miliarius* | 23.5 | Native | | |
| Eastern spadefoot | *Scaphiopus holbrooki* | 26.8 | Native | | |
| Jamaican giant anole | *Anolis garmani* | 27.8 | Exotic | Omnivore | Arboreal |

| | | | | | |
|---|---|---|---|---|---|
| North curlytail lizard | *Leiocephalus carinatus* | 31.58 | Exotic | Carnivore | Arboreal |
| Milk snake | *Lampropeltis triangulum* | 31.85 | Native | | |
| Coral snake | *Micrurus fulvius* | 40 | Native | | |
| Island glass lizard | *Ophisaurus compressus* | 45 | Native-E | Carnivore | Fossorial |
| Gopher frog | *Rana capito* | 51.02 | Native-E | Carnivore | Fossorial |
| Eastern glass lizard | *Ophisaurus ventralis* | 59.7 | Native | | |
| Slender glass lizard | *Ophisaurus attenuatus* | 81.77 | Native | | |
| Knight anole | *Anolis equestris* | 82.1 | Exotic | Carnivore | Arboreal |
| Brown basilisk | *Basiliscus vittatus* | 99.95 | Exotic | Carnivore | Ground |
| Black racer | *Coluber constrictor* | 102.5 | Native | | |
| Corn snake | *Elaphe guttata* | 106.41 | Native | | |
| Giant ameiva | *Ameiva ameiva* | 108.89 | Exotic | Carnivore | Ground |
| Eastern hognose snake | *Heterondon platyrhinos* | 115 | Native | | |
| Giant toad | *Bufo marinus* | 126.07 | Exotic | Carnivore | Ground |
| Pine snake | *Pituophis melanoleuc* | 140 | Native-E | Carnivore | Fossorial |
| Yellow rat snake | *Elaphe obsoleta* | 193.86 | Native | | |
| Kingsnake | *Lampropeltis getulus* | 250 | Native | | |
| Eastern coachwhip | *Masticophis flagellum* | 260 | Native | | |
| Indigo snake | *Drymarchon corais* | 450 | Native-E | Carnivore | Ground |
| Eastern diamond-back | *Crotalus adamanteus* | 547 | Native | | |
| Cottonmouth | *Aqkistrodon piscivorus* | 700 | Native | | |
| Spinytail iguana | *Ctenosaura pectinata* | 975 | Exotic | Omnivore | Arboreal |
| Gopher tortoise | *Gopherus polyphemus* | 2633.93 | Native-E | Herbivore | Ground |
| Green iguana | *Iguana iguana* | 4605 | Exotic | Omnivore | Arboreal |

**Mammals**

| | | | | | |
|---|---|---|---|---|---|
| Eastern pipistrel | *Pipistrellus subflavus* | 4.75 | Native | | |
| Least shrew | *Cryptotis parva* | 5.5 | Native | | |
| Evening bat | *Nycticeius humeralis* | 8 | Native | | |
| Seminole bat | *Lasiurus seminolus* | 10.5 | Native | | |
| E harvest mouse | *Peromyscus polionotus* | 11.5 | Native | | |
| Old-field mouse | *Reithrodontomys humulis* | 11.5 | Native | | |
| Brazilian free-tailed bat | *Tadarida brasiliensis* | 12.5 | Native | | |
| Short-tailed shrew | *Blarina carolinensis* | 16.5 | Native-E | Carnivore | Ground |
| Yellow bat | *Lasiurus intermedius* | 17 | Native | | |
| House mouse | *Mus musculus* | 17 | Exotic | Herbivore | Ground |
| Florida mouse | *Peromyscus floridanus* | 37 | Native-E | Omnivore | Ground |
| Mastiff bat | *Eumops glaucinus* | 38 | Native-E | Herbivore | Volant |
| Cotton mouse | *Peromyscus gossypinus* | 39.5 | Native | | |
| Rice rat | *Oryzomys palustris* | 60 | Native | | |
| S flying squirrel | *Glaucomys volans* | 64.5 | Native | | |
| Eastern mole | *Scalopus aquaticus* | 103.5 | Native | | |
| Hispid cotton rat | *Sigmodon hispidus* | 155.5 | Native | | |
| Long-tailed weasel | *Mustela frenata* | 205.25 | Native | | |
| Black rat | *Rattus rattus* | 212.5 | Exotic | Omnivore | Ground |
| Norway rat | *Rattus norvegicus* | 241.5 | Exotic | Omnivore | Ground |
| Roundtailed muskrat | *Neofiber alleni* | 243 | Native-E | Herbivore | Ground |
| Eastern woodrat | *Neotoma floridana* | 291 | Native | | |
| Gray squirrel | *Sciurus carloinensis* | 533 | Native | | |
| Red-bellied squirrel | *Sciurus aureogaster* | 556 | Exotic | Herbivore | Ground |
| E spotted skunk | *Spilogale putorius* | 596 | Native | | |
| Mink | *Mustela vison* | 924.75 | Native-E | Carnivore | Water |

| | | | | | |
|---|---|---|---|---|---|
| Fox squirrel | *Sciurus niger* | 953 | Native-E | Herbivore | Ground |
| Marsh rabbit | *Sylvilagus floridanus* | 1350 | Native | | |
| Cottontail | *Sylvilagus palustris* | 1350 | Native | | |
| Black-tailed jack rabbit | *Lepus californicus* | 2200 | Exotic | Herbivore | Ground |
| Domestic cat | *Felis catus* | 3900 | Exotic | Carnivore | Ground |
| Striped skunk | *Mephitis mephitis* | 4500 | Native | | |
| Gray fox | *Urocyon cinereoargenteus* | 4500 | Native | | |
| Opposum | *Didelphis virginiana* | 4950 | Native | | |
| Armadillo | *Dasypus novemcinctus* | 5600 | Exotic | Omnivore | Ground |
| Red fox | *Vulpes vulpes* | 5600 | Exotic | Carnivore | Ground |
| River otter | *Lutra canadensis* | 7850 | Native | | |
| Raccoon | *Procyon lotor* | 10600 | Native | | |
| Bobcat | *Lynx rufus* | 11200 | Native | | |
| Coyote | *Canis latrans* | 15500 | Exotic | Carnivore | Ground |
| Feral dog | *Canis familiaris* | 16700 | Exotic | Carnivore | Ground |
| Red wolf | *Canis rufus* | 24750 | Native-E | Carnivore | Ground |
| Cougar | *Felis concolor* | 63000 | Native-E | Carnivore | Ground |
| Deer | *Odocoileus virginianus* | 87175 | Native | | |
| Hog | *Sus scrofa* | 115000 | Exotic | Omnivore | Ground |
| Black bear | *Ursus americanus* | 152000 | Native-E | Omnivore | Ground |

[1] Body mass estimates for birds were from Dunning (1993), Forys and Allen (1998) or Low (1992). Body mass estimates for herpetofauna were from Forys and Allen (1998), Greenberg (1993), unpublished data obtained from K. Dodd or C. Sekerak, or were obtained by weighing a sample of specimens from the Florida Museum of Natural History. Body mass estimates for mammals were from Burt and Grossenheider (1976), Emmons (1990), Forys and Allen (1998), Scott and Causey (1973), or Whitaker (1996).

# APPENDIX B
# BODY MASS AND LUMP STRUCTURE OF VERTEBRATES IN SOUTH FLORIDA

| Common Name | *Latin name* | Body mass | Gap Statistic | Lump |
|---|---|---|---|---|
| **Avifauna** | | | | |
| Ruby-throated Hummingbird | *Archilochus colubris* | 0.4983 | **0.80153** | 1 |
| Blue-gray Knatcatcher | *Polioptila caerulea* | 0.7782 | 0.54473 | 1 |
| Prairie Warbler | *Dendroica discolor* | 0.88 | 0.28639 | 1 |
| Northern Parula | *Parula americana* | 0.9345 | 0.17573 | 1 |
| Yellow-throated Warbler | *Dendroica dominica* | 0.9731 | 0.00043 | 1 |
| Yellow Warbler | *Dendroica petechia* | 0.9777 | 0.08647 | 1 |
| Common Yellowthroat | *Geothlypis trichas* | 1.0043 | 0.00028 | 1 |
| Brown-headed Nuthatch | *Sitta pusilla* | 1.0086 | 0.35915 | 1 |
| White-eyed Vireo | *Vireo griseus* | 1.0569 | 0.08509 | 1 |
| Pine Warbler | *Dendroica pinus* | 1.08 | **0.71237** | 1 |
| Prothonotary Warbler | *Protonotaria citrea* | 1.1553 | 0.44304 | 2 |
| Northern Rough-winged Swallow | *Stelgidopteryx serripennis* | 1.2014 | 0.00012 | 2 |
| Barn Swallow | *Hirundo rustica* | 1.20 | 0.0791755 | 2 |
| Red-eyed Vireo | *Vireo olivaceus* | 1.22 | 0.0051652 | 2 |
| Grasshopper Sparrow | *Ammodramus savannarum* | 1.23 | 0.1336683 | 2 |
| Black-whiskered Vireo | *Vireo altiloquus* | 1.25 | 0.087686 | 2 |
| Carolina Wren | *Thryothorus ludovicianus* | 1.27 | 0.3055441 | 2 |
| Bachman's Sparrow | *Aimophilia aestivalis* | 1.31 | 0.2517303 | 2 |
| Tufted Titmouse | *Parus bicolor* | 1.33 | 0.3011789 | 2 |
| Seaside Sparrow | *Ammodramus maritimus* | 1.37 | 0.004917 | 2 |
| Chimney Swift | *Chaetura pelagica* | 1.37 | **0.6975809** | 2 |
| Downy Woodpecker | *Picoides pubescens* | 1.43 | 0.1147242 | 3 |
| Summer Tanager | *Piranga rubra* | 1.45 | 0.2784221 | 3 |
| Common Ground-Dove | *Columbigallina passerina* | 1.48 | 0.1592183 | 3 |

| | | | | |
|---|---|---|---|---|
| Eastern Bluebird | *Sialia sialis* | 1.50 | 0.2323734 | 3 |
| Great Crested Flycatcher | *Myiarchus crinitus* | 1.53 | **0.9081452** | 3 |
| Rufous-sided Towhee | *Pipilo erythrophthalmus* | 1.61 | 0.3761179 | 4 |
| Eastern Kingbird | *Tyrannus tyrannus* | 1.6395 | 0.000000 | 4 |
| Red-cockaded Woodpecker | *Picoides borealis* | 1.6395 | 0.000281 | 4 |
| Gray Kingbird | *Tyrannus dominicensis* | 1.6415 | 0.015137 | 4 |
| Northern Cardinal | *Cardinalis cardinalis* | 1.6498 | 0.275849 | 4 |
| Loggerhead Shrike | *Lanius ludovicianus* | 1.6758 | 0.027081 | 4 |
| Northern Mockingbird | *mimus polyglottos* | 1.6857 | 0.015809 | 4 |
| Puple Martin | *Progne subis* | 1.6937 | 0.282456 | 4 |
| Red-winged Blackbird | *Agelaius phoeniceus* | 1.7206 | **0.863316** | 4 |
| Common Nighthawk | *Chordeiles minor* | 1.7889 | 0.000081 | 5 |
| Red-bellied Woodpecker | *Melanerpes carolinus* | 1.7903 | 0.087049 | 5 |
| Mangrove Cuckoo | *Coccyzus minor* | 1.8055 | 0.000008 | 5 |
| Yellow-billed Cuckoo | *Coccyzus americanus* | 1.8062 | 0.099795 | 5 |
| Hairy Woodpecker | *Picoides villosus* | 1.8212 | 0.113154 | 5 |
| Brown Thrasher | *Toxostoma rufum* | 1.8376 | 0.127076 | 5 |
| Red-headed Woodpecker | *Melanerpes erythrocephalus* | 1.8549 | **0.691907** | 5 |
| Scrub Jay | *Aphelocoma coerulescens* | 1.9042 | 0.410927 | 6 |
| Least Bittern | *Ixobrychus exilis* | 1.936 | 0.000336 | 6 |
| Blue Jay | *Cyanocitta cristata* | 1.9385 | 0.046732 | 6 |
| Eastern Meadowlark | *Sturnella magna* | 1.9494 | 0.473535 | 6 |
| Killdeer | *Charadrius vociferus* | 1.9848 | **0.733798** | 6 |
| Carolina Parakeet | *Conuropsis carolinensis* | 2.0374 | 0.142798 | 7 |
| Common Grackle | *Quiscalus quiscula* | 2.055 | 0.012775 | 7 |
| American Kestrel | *Falco sparverius* | 2.0626 | 0.066695 | 7 |
| Mourning Dove | *Zenaida macroura* | 2.0755 | 0.001891 | 7 |
| Chuck-will's-widow | *Caprimulgus carolinensis* | 2.0792 | 0.573970 | 7 |

| | | | | |
|---|---|---|---|---|
| Northern Flicker | *Colaptes auratus* | 2.1206 | **0.705000** | 7 |
| Belted Kingfisher | *Ceryle alcyon* | 2.1703 | 0.188153 | 8 |
| Burrowing Owl | *Speotyto (Athene) cunicularia* | 2.1903 | 0.365794 | 8 |
| Black-necked Stilt | *Himantopus mexicanus* | 2.2201 | 0.000086 | 8 |
| Boat-tailed Grackel | *Quiscalus major* | 2.2214 | 0.350756 | 8 |
| Northern Bobwhite | *Colinus virginianus* | 2.2504 | 0.009026 | 8 |
| Eastern Screech-Owl | *Otus asio* | 2.2565 | 0.552722 | 8 |
| American Woodcock | *Scolopax minor* | 2.2956 | 0.305175 | 8 |
| Purple Gallinule | *Porphyrula martinica* | 2.3222 | 0.001982 | 8 |
| Green Heron | *Butorides virescens* | 2.3263 | 0.009237 | 8 |
| Willet | *Catoptrophorus semipalmatus* | 2.3324 | **0.823293** | 8 |
| White-crowned Pigeon | *Columba leucocphala* | 2.3927 | 0.360241 | 9 |
| Fish Crow | *Corvus ossifragus* | 2.4216 | 0.458885 | 9 |
| Pileated Woodpecker | *Dryocopus pileatus* | 2.4548 | 0.000975 | 9 |
| Clapper Rail | *Rallus longirostris* | 2.4579 | 0.095644 | 9 |
| Common Moorhen | *Gallinula chloropus* | 2.4728 | 0.013898 | 9 |
| White-tailed Kite | *Elanus leucurus* | 2.4807 | 0.578854 | 9 |
| Little Blue Heron | *Florida caerulea* | 2.52 | 0.041159 | 9 |
| King Rail | *Rallus elegans* | 2.5308 | 0.312848 | 9 |
| Snowy Egret | *Egretta thula* | 2.5569 | 0.060301 | 9 |
| Tricolored Heron | *Egretta tricolor* | 2.5694 | 0.019053 | 9 |
| Snail Kite | *Rostrhamus sociabilis* | 2.5775 | **0.874571** | 9 |
| Pied-bill Grebe | *Podilymbus podiceps* | 2.6454 | 0.003610 | 10 |
| American Swallow-tailed Kite | *Elanoides forficatus* | 2.65 | 0.000008 | 10 |
| American Crow | *Corvus brachyrhynchos* | 2.6513 | 0.000349 | 10 |
| Reddish Egret | *Egretta rufescens* | 2.6532 | 0.577108 | 10 |
| Short-tailed Hawk | *Buteo brachyurus* | 2.6946 | 0.076965 | 10 |
| Ivory-billed Woodpecker | *Campephilus principalis* | 2.7084 | 0.037117 | 10 |

| | | | | |
|---|---|---|---|---|
| Barn Owl | *Tyto alba* | 2.7189 | 0.337252 | 10 |
| Red-shouldered Hawk | *Buteo lineatus* | 2.7474 | 0.494786 | 10 |
| Hooded Merganser | *Lophodytes cucullatus* | 2.7853 | 0.114489 | 10 |
| Glossy Ibis | *Plegadis falcinellus* | 2.8019 | 0.004738 | 10 |
| American Coot | *Fulica americana* | 2.8075 | 0.263435 | 10 |
| Yellow-crowned Night-Heron | *Nyctanassa violacea* | 2.8341 | 0.072414 | 10 |
| American Bittern | *Botaurus lentiginosus* | 2.8488 | 0.006518 | 10 |
| Barred Owl | *Strix varia* | 2.8552 | **0.905877** | 10 |
| Great Egret | *Casmerodius albus* | 2.9413 | 0.001018 | 11 |
| Black-crowned Night-Heron | *Nycticorax nycticorax* | 2.946 | 0.003080 | 11 |
| Crested Caracara | *Caracara (Polyborus) plancus* | 2.9511 | 0.000173 | 11 |
| White Ibis | *Eudocimus albus* | 2.9542 | 0.499973 | 11 |
| Mottled Duck | *Anas fulvigula* | 2.9996 | 0.027149 | 11 |
| Great Horned Owl | *Bubo virginianus* | 3.012 | 0.109420 | 11 |
| Limpkin | *Aramus guarauna* | 3.0334 | 0.075717 | 11 |
| Red-tailed Hawk | *Buteo jamaicensis* | 3.0515 | **0.904735** | 11 |
| Turkey Vulture | *Cathartes aura* | 3.1664 | 0.001000 | 12 |
| Osprey | *Pandion haliaetus* | 3.1719 | 0.007371 | 12 |
| Roseate Spoonbill | *Ajaia ajaja* | 3.1826 | 0.237373 | 12 |
| Double-crested Cormorant | *Phalacrocorax auritus* | 3.2238 | 0.641414 | 12 |
| Black Vulture | *Coragyps atratus* | 3.3182 | 0.247536 | 12 |
| Wood Stork | *Mycteria americana* | 3.3758 | 0.000012 | 12 |
| Great Blue Heron | *Ardea herodias* | 3.3784 | **0.925151** | 12 |
| Bald Eagle | *Haliaeetus leucocephalus* | 3.6758 | 0.005219 | 13 |
| Sandhill Crane | *Grus canadensis* | 3.7066 | 0.025702 | 13 |
| Wild Turkey | *Meleagris gallopavo* | 3.7643 | 0.000000 | 13 |

**Non-native avifauna**

| | | |
|---|---|---|
| Cave Swallow | *Hirundo fulva* | 1.3096 |
| House Finch | *Carpodacus mexicanus* | 1.3304 |
| Red-whiskered Bulbul | *Pyconotus jocosus* | 1.4378 |
| House Sparrow | *Passer domesticus* | 1.4425 |
| Budgerigar | *Melopsittacus undulatus* | 1.4624 |
| Shiny Cowbird | *Molothrus bonariensis* | 1.5478 |
| Red-crested Cardinal | *Paroaria coronata* | 1.6335 |
| Brown-headed Cowbird | *Molothrus ater* | 1.6425 |
| Spot-breasted Oriole | *Icterus pectoralis* | 1.6484 |
| Canary-winged Parakeet | *Brotogeris versicoluras* | 1.781 |
| European Starling | *Sturnus vulgaris* | 1.9154 |
| Monk Parakeet | *Myiopsitta monachus* | 2.0043 |
| Smooth-billed Ani | *Crotophaga ani* | 2.0212 |
| Dusky-headed Parakeet | *Aratinga weddellii* | 2.0334 |
| Common Myna | *Acridotheres tristis* | 2.0414 |
| Rose-ringed Parakeet | *Psittacula krameria* | 2.1055 |
| Black-hooded Parakeet | *Nandaynus nenday* | 2.1072 |
| Ringed Turtle-Dove | *Streptopelia risoria* | 2.1335 |
| Eurasian Collared-Dove | *Streplopelia decaoto* | 2.1732 |
| White-winged Dove | *Zenaida asiatica* | 2.1847 |
| Blue-crowned Parakeet | *Aratinga acuticaudata* | 2.2175 |
| Hill Myna | *Gracula religiosa* | 2.2833 |
| Red-masked Parakeet | *Aratinga erythrogenys* | 2.301 |
| Mitred Parakeet | *Aratinga mitrata* | 2.301 |
| Red-crowned Parrot | *Amazona viridigensalis* | 2.4683 |
| Orange-winged Parrot | *Amazona amazonica* | 2.5289 |
| Cattle Egret | *Bubulcus ibis* | 2.5289 |

| | | | | |
|---|---|---|---|---|
| Chestnut-fronted Macaw | *Ara severa* | 2.5403 | | |
| Rock Dove | *Columba livia* | 2.5496 | | |
| Black Francolin | *Francolinus francolinus* | 2.6561 | | |
| Yellow-headed Parrot | *Amazona oratrix* | 2.699 | | |
| Fulvous Whisting-Duck | *Dendrocygna biocolor* | 2.8513 | | |
| Black-bellied Whistling Duck | *Dendrocygna autumnalis* | 2.9196 | | |
| Mallard | *Anas platyrhynchos* | 3.0342 | | |
| Muscovy duck | *Cairina moschata* | 3.3924 | | |
| Canada Goose | *Branta canadensis canadensis* | 3.5519 | | |
| Common Peafowl | *Pavo cristatus* | 3.622 | | |

**Herpetofauna**

| | | | | |
|---|---|---|---|---|
| Little grass frog | *Pseudacris ocularis* | -0.677780705 | 0.394855 | 1 |
| Squirrel treefrog | *Hyla squirella* | -0.431798276 | 0.22466281 | 1 |
| Florida cricket frog | *Acris gryllus* | -0.30980392 | 0.40028877 | 1 |
| Dwarf salamander | *Eurycea quadridigita* | -0.17327748 | 0.06154113 | 1 |
| Florida chorus frog | *Pseudacris nigrita* | -0.124938737 | 0.22783063 | 1 |
| Ground skink | *Scincella laterale* | -0.045757491 | **0.72998523** | 1 |
| Mole skink | *Eumeces egregius* | 0.113943352 | 0.00294209 | 2 |
| Rim rock crowned snake | *Tantilla oolitica* | 0.127104798 | 0.00303758 | 2 |
| Oak toad | *Bufo quercicus* | 0.139879086 | 0.0643721 | 2 |
| E narrow-mouthed toad | *Gastrophryne carolinensis* | 0.176091259 | 0.31571473 | 2 |
| Spring peeper | *Hyla crucifer* | 0.249198357 | 0.04534168 | 2 |
| Crowned snake | *Tantilla relicta* | 0.278753601 | 0.2681643 | 2 |
| Green anole | *Anolis carolinensis* | 0.342422681 | 0.43018303 | 2 |
| Bark anole | *Anolis distichus* | 0.425371166 | 0.00261585 | 2 |
| Pine woods treefrog | *Hyla femoralis* | 0.436957331 | 0.07895394 | 2 |

| | | | | |
|---|---|---|---|---|
| Ringnecked snake | *Diadophis punctatus* | 0.471291711 | 0.37910326 | 2 |
| Southern leopard frog | *Rana sphenocephala* | 0.546542663 | 0.31689958 | 2 |
| Florida scrub lizard | *Seloperus woodi* | 0.612783857 | **0.47389407** | 2 |
| Green treefrog | *Hyla cinerea* | 0.698970004 | 0 | 3 |
| Brown snake | *Storeria dekayi* | 0.698970004 | **0.56597255** | 3 |
| Mud snake | *Farancia abacura* | 0.797267541 | **0.61604484** | 3 |
| Six-lined racerunner | *Cnemidophorus sexlineatus* | 0.903089987 | 0.10408428 | 3 |
| Scarlet snake | *Cemophora coccinea* | 0.941014244 | 0.47183601 | 3 |
| Southeastern 5-Lined skink | *Eumeces inexpectatus* | 1.025305865 | 0.01651613 | 3 |
| Southern toad | *Bufo terrestris* | 1.045322979 | 0.00009284 | 3 |
| Ribbon snake | *Thamnophis sauritus* | 1.049218023 | 0.05513434 | 3 |
| Pig frog | *Rana grylio* | 1.078819183 | 0.43768113 | 3 |
| Florida box turtle | *Terepene carolina* | 1.161368002 | 0.07278988 | 3 |
| Garter snake | *Thamnophis sirtalis* | 1.194514342 | 0.00008387 | 3 |
| Barking treefrog | *Hyla gratiosa* | 1.199233931 | 0.40223885 | 3 |
| Rough green snake | *Opheodrys aestivus* | 1.278753601 | 0.47207769 | 4 |
| Pigmy rattlesnake | *Sistrurus miliarius* | 1.371067862 | 0.19993831 | 4 |
| Eastern spadefoot | *Scaphiopus holbrooki* | 1.428134794 | 0.30872366 | 4 |
| Milk snake | *Lampropeltis triangulum* | 1.503132162 | 0.4513608 | 4 |
| Coral snake | *Micrurus fulvius* | 1.602059991 | 0.12403968 | 4 |
| Island glass lizard | *Ophisaurus compressus* | 1.653212514 | 0.13392983 | 4 |
| Gopher frog | *Rana capito* | 1.707757478 | 0.20119742 | 4 |
| Eastern glass lizard | *Ophisaurus ventralis* | 1.775950082 | **0.57871144** | 4 |
| Slender glass lizard | *Ophisaurus attenuatus* | 1.912593998 | 0.32997495 | 5 |
| Black racer | *Coluber constrictor* | 2.010723865 | 0.00269991 | 5 |
| Corn snake | *Elaphe guttata* | 2.026982443 | 0.02567852 | 5 |
| Eastern hognose snake | *Heterondon platyrhinos* | 2.06069784 | 0.23300717 | 5 |
| Pine snake | *Pituophis melanoleucus* | 2.146128036 | **0.46964454** | 5 |

| | | | | |
|---|---|---|---|---|
| Yellow rat snake | *Elaphe obsoleta* | 2.287488208 | 0.26820168 | 6 |
| Kingsnake | *Lampropeltis getulus* | 2.397940009 | 0.00135391 | 6 |
| Eastern coachwhip | *Masticophis flagellum* | 2.414973348 | **0.62978853** | 6 |
| Indigo snake | *Drymarchon corais* | 2.653212514 | 0.06255632 | 7 |
| Eastern diamond-back | *Crotalus adamanteus* | 2.737987326 | 0.0811883 | 7 |
| Cottonmouth | *Aqkistrodon piscivorus* | 2.84509804 | **0.59142509** | 7 |
| Gopher tortoise | *Gopherus polyphemus* | 3.420604229 | 0 | 7 |

**Non-native herpetofauna**

| | | |
|---|---|---|
| Greenhouse frog | *Eleutherodactylus planirostris* | -0.22184875 |
| Reef gecko | *Sphaerodactylus notatus* | -0.124938737 |
| Brahminy blind snake | *Ramphotyphlops braminus* | -0.036212173 |
| Oscellated gecko | *Sphaerodactylus argus* | -0.007790244 |
| Ashy gecko | *Spaerodactylus elegans* | 0.105510185 |
| Yellowhead gecko | *Gonatodes albogulari* | 0.289811839 |
| Indo-pacific gecko | *Hemidactylus garnoti* | 0.441083884 |
| Mediterrean gecko | *Hemidactylis turcicus* | 0.536684673 |
| Brown anole | *Anolis sagrei* | 0.714162046 |
| Peurtoa Rican coqui | *Eleutherodactylus coqui* | 0.722304787 |
| Crested anole | *Anolis cristatellus* | 0.953807998 |
| Rainbow whiptail | *Cnemidophorus lemniscatus* | 1.117370741 |
| Cuban treefrog | *Osteopilus septentrionalis* | 1.301029996 |
| Jamaican giant anole | *Anolis garmani* | 1.44410728 |
| North curlytail lizard | *Leiocephalus carinatus* | 1.499412126 |
| Knight anole | *Anolis equestris* | 1.914343157 |
| Brown basilisk | *Basiliscus vittatus* | 1.999761072 |
| Giant ameiva | *Ameiva ameiva* | 2.036997969 |
| Giant toad | *Bufo marinus* | 2.100611753 |

| | | | | |
|---|---|---|---|---|
| Spinytail iguana | *Ctenosaura pectinata* | 2.989004616 | | |
| Green iguana | *Iguana iguana* | 3.663229635 | | |
| **Mammals** | | | | |
| Eastern pipistrel | *Pipistrellus subflavus* | 0.67669361 | 0.031187452 | 1 |
| Least shrew | *Cryptotis parva* | 0.740362689 | 0.369561213 | 1 |
| Evening bat | *Nycticeius humeralis* | 0.903089987 | 0.266980044 | 1 |
| Seminole bat | *Lasiurus seminolus* | 1.021189299 | 0.021321973 | 1 |
| E harvest mouse | *Peromyscus polionotus* | 1.06069784 | 0 | 1 |
| Old-field mouse | *Reithrodontomys humulis* | 1.06069784 | 0.018837852 | 1 |
| Brazilian free-tailed bat | *Tadarida brasiliensis* | 1.096910013 | 0.329051291 | 1 |
| Short-tailed shrew | *Blarina carolinensis* | 1.217483944 | 0.000577064 | 1 |
| Yellow bat | *Lasiurus intermedius* | 1.230448921 | **0.91072913** | 1 |
| Florida mouse | *Peromyscus floridanus* | 1.568201724 | 0.000332665 | 2 |
| Mastiff bat | *Eumops glaucinus* | 1.579783597 | 0.001292722 | 2 |
| Cotton mouse | *Peromyscus gossypinus* | 1.596597096 | **0.522366144** | 2 |
| Rice rat | *Oryzomys palustris* | 1.77815125 | 0.008011304 | 2 |
| S flying squirrel | *Glaucomys volans* | 1.809559715 | **0.559964265** | 2 |
| Eastern mole | *Scalopus aquaticus* | 2.01494035 | 0.431523723 | 3 |
| Hispid cotton rat | *Sigmodon hispidus* | 2.191730393 | 0.217718994 | 3 |
| Long-tailed weasel | *Mustela frenata* | 2.312283166 | 0.069958228 | 3 |
| Roundtailed muskrat | *Neofiber alleni* | 2.385606274 | 0.08106297 | 3 |
| Eastern woodrat | *Neotoma floridana* | 2.463892989 | **0.677553255** | 3 |
| Gray squirrel | *Sciurus carloinensis* | 2.726727209 | 0.021487972 | 3 |
| E spotted skunk | *Spilogale putorius* | 2.77524626 | **0.446647081** | 3 |
| Mink | *Mustela vison* | 2.96602434 | 0.000289026 | 4 |
| Fox squirrel | *Sciurus niger* | 2.979092901 | 0.288152973 | 4 |

| | | | | |
|---|---|---|---|---|
| Marsh rabbit | *Sylvilagus floridanus* | 3.130333768 | 0 | 4 |
| Cottontail | *Sylvilagus palustris* | 3.130333768 | **0.931419962** | 4 |
| Striped skunk | *Mephitis mephitis* | 3.653212514 | 0 | 5 |
| Gray fox | *Urocyon cinereoargenteus* | 3.653212514 | 0.008321283 | 5 |
| Opposum | *Didelphis virginiana* | 3.694605199 | 0.381136368 | 5 |
| River otter | *Lutra canadensis* | 3.894869657 | 0.155049363 | 5 |
| Raccoon | *Procyon lotor* | 4.025305865 | 0.000866801 | 5 |
| Bobcat | *Lynx rufus* | 4.049218023 | **0.579023254** | 5 |
| Red wolf | *Canis rufus* | 4.393575203 | **0.507768403** | 5 |
| Cougar | *Felis concolor* | 4.799340549 | 0.044146408 | 6 |
| Deer | *Odocoileus virginianus* | 4.940391956 | 0.119695651 | 6 |
| Black bear | *Ursus americanus* | 5.181843588 | 0 | 6 |

**Non-native mammals**

| | | |
|---|---|---|
| House mouse | *Mus musculus* | 1.230448921 |
| Black rat | *Rattus rattus* | 2.327358934 |
| Norway rat | *Rattus norvegicus* | 2.382917135 |
| Red-bellied squirrel | *Sciurus aureogaster* | 2.745074792 |
| Black-tailed jack rabbit | *Lepus californicus* | 3.342422681 |
| Domestic cat | *Felis catus* | 3.591064607 |
| Armadillo | *Dasypus novemcinctus* | 3.748188027 |
| Red fox | *Vulpes vulpes* | 3.748188027 |
| Coyote | *Canis latrans* | 4.190331698 |
| Feral dog | *Canis familiaris* | 4.222716471 |
| Wild hog | *Sus scrofa* | 5.06069784 |

# APPENDIX C
# SUCCESSFUL AND UNSUCCESSFUL AVIAN INTRODUCTIONS IN SOUTH FLORIDA

| Species[1] | Status | Log mass | Success | Gap | Near | Edge | Years | Ncong | NIScong |
|---|---|---|---|---|---|---|---|---|---|
| *Carpodacus mexicanus* | 3 | 1.3304 | 1 | 0 | 0.0041 | 0.0425 | 16 | N | N |
| *Pyconotus jocosus* | 3 | 1.4378 | 1 | 0 | 0.0064 | 0.0064 | 38 | N | N |
| *Melopsittacus undulatus* | 3 | 1.4624 | 1 | 0 | 0.0122 | 0.0310 | 36 | N | N |
| *Paroaria coronata* | 3 | 1.6335 | 1 | 0 | 0.006 | 0.0260 | 36 | N | N |
| *Brotogeris versicoluras* | 3 | 1.781 | 1 | 1 | 0.0079 | 0.0079 | 29 | N | N |
| *Myiopsitta monachus* | 3 | 2.0043 | 1 | 1 | 0.0331 | 0.0331 | 24 | N | N |
| *Aratinga weddellii* | 3 | 2.0334 | 1 | 1 | 0.004 | 0.0040 | 12 | N | Y |
| *Acridotheres tristis* | 3 | 2.0414 | 1 | 0 | 0.004 | 0.0040 | 13 | N | N |
| *Psittacula krameria* | 3 | 2.1055 | 1 | 0 | 0.0151 | 0.0151 | 31 | N | N |
| *Nandaynus nenday* | 3 | 2.1072 | 1 | 0 | 0.0134 | 0.0134 | 27 | N | N |
| *Streptopelia risoria* | 3 | 2.1335 | 1 | 1 | 0.0129 | 0.0129 | 74 | N | N |
| *Streptopelia decaoto* | 3 | 2.1732 | 1 | 0 | 0.0029 | 0.0029 | 18 | N | Y |
| *Zenaida asiatica* | 3 | 2.1847 | 1 | 0 | 0.0056 | 0.0144 | 37 | Y | N |
| *Aratinga acuticaudata* | 3 | 2.2175 | 1 | 0 | 0.0026 | 0.0472 | 14 | N | N |
| *Gracula religiosa* | 3 | 2.2833 | 1 | 0 | 0.0123 | 0.0491 | 28 | N | N |
| *Aratinga erythrogenys* | 3 | 2.301 | 1 | 0 | 0.0054 | 0.0314 | 13 | N | Y |
| *Aratinga mitrata* | 3 | 2.301 | 1 | 0 | 0.0054 | 0.0314 | 11 | N | Y |
| *Amazona viridigensalis* | 3 | 2.4683 | 1 | 0 | 0.0045 | 0.0756 | 26 | N | N |
| *Amazona amazonica* | 3 | 2.5289 | 1 | 0 | 0.0089 | 0.0486 | 23 | N | Y |
| *Ara severa* | 3 | 2.5403 | 1 | 0 | 0.0095 | 0.0372 | 19 | N | N |
| *Francolinus francolinus* | 3 | 2.6561 | 1 | 0 | 0.0029 | 0.0107 | 35 | N | N |
| *Amazona oratrix* | 3 | 2.699 | 1 | 0 | 0.0044 | 0.0536 | 24 | N | Y |
| *Dendrocygna biocolor* | 3 | 2.8513 | 1 | 0 | 0.0039 | 0.0039 | 46 | N | N |
| *Dendrocygna autumnalis* | 3 | 2.9196 | 1 | 1 | 0.0217 | 0.0217 | 31 | N | Y |
| *Anas platyrhynchos* | 3 | 3.0342 | 1 | 0 | 0.0008 | 0.0173 | 137 | Y | N |
| *Cairina moschata* | 3 | 3.3924 | 1 | 1 | 0.014 | 0.0140 | 29 | N | N |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Pavo cristatus* | 3 | 3.622 | 1 | 1 | 0.0538 | 0.0538 | 24 | N | N |
| *Serinus mozambicus* | 11 | 1.02531 | 0 | 0 | 0.0167 | 0.0547 | 13 | N | N |
| *Lonchura punctulata* | 11 | 1.13354 | 0 | 1 | 0.0218 | 0.0218 | 32 | N | N |
| *Padda oryzivora* | 11 | 1.39445 | 0 | 1 | 0.0216 | 0.0216 | 36 | N | N |
| *Nymphicus hollandicus* [2] | 11 | 1.99739 | 0 | 1 | 0.0126 | 0.0126 | 31 | N | N |
| *Acridotheres cristatellus* | 11 | 2.05308 | 0 | 0 | 0.0019 | 0.0157 | 13 | N | Y |
| *Eos bornea* [2] | 11 | 2.23045 | 0 | 0 | 0.009 | 0.0601 | 11 | N | N |
| *Amazona ventralis* [2] | 11 | 2.38021 | 0 | 1 | 0.0125 | 0.0125 | 21 | N | Y |
| *Amazona finschi* | 11 | 2.48001 | 0 | 0 | 0.0007 | 0.0873 | 21 | N | Y |
| *Callonetta leucophrys* | 11 | 2.57054 | 0 | 0 | 0.0011 | 0.0070 | 21 | N | N |
| *Aramides cajanea* | 11 | 2.59879 | 0 | 1 | 0.0213 | 0.0213 | 31 | N | N |
| *Amazona aestiva* | 11 | 2.60206 | 0 | 1 | 0.0246 | 0.0246 | 17 | N | Y |
| *Amazona autumnalis* | 11 | 2.61909 | 0 | 1 | 0.0263 | 0.0263 | 16 | N | Y |
| *Amazona auropalliata* [2] | 11 | 2.68124 | 0 | 0 | 0.0134 | 0.0358 | 14 | N | Y |
| *Gallus gallus* | 11 | 2.82737 | 0 | 0 | 0.0067 | 0.0278 | 30 | N | N |
| *Buteogallus urubitinga* | 11 | 2.99826 | 0 | 0 | 0.0007 | 0.0532 | 23 | N | N |
| *Numida meleagris* | 11 | 3.11361 | 0 | 1 | 0.0528 | 0.0528 | 51 | N | N |
| *Alopochen aigyptiaca* | 11 | 3.2701 | 0 | 0 | 0.0481 | 0.1037 | 31 | N | N |
| *Anser cygnoides* | 11 | 3.49831 | 0 | 1 | 0.1199 | 0.1199 | 10 | N | N |
| *Anser anser* | 11 | 3.51963 | 0 | 1 | 0.1412 | 0.1412 | 8 | N | N |
| *cygnus olor* | 11 | 4.0308 | 0 | 1 | 0.2665 | 0.2665 | 23 | N | N |
| *Paroaria gularis* | 12 | 1.34242 | 0 | 0 | 0.0079 | 0.0305 | 31 | N | Y |
| *Brotogeris jugularis* | 12 | 1.80106 | 0 | 0 | 0.0044 | 0.0122 | 27 | N | Y |
| *Aratinga canicularis* | 12 | 1.87622 | 0 | 1 | 0.0213 | 0.0213 | 24 | N | Y |
| *Pyrrhura frontalis* | 12 | 1.9039 | 0 | 1 | 0.0003 | 0.0003 | 11 | N | N |
| *Poicephalus senegalus* | 12 | 2.16732 | 0 | 1 | 0.003 | 0.0030 | 13 | N | N |
| *Amazona albifrons* | 12 | 2.31387 | 0 | 0 | 0.0083 | 0.0185 | 23 | N | Y |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Vanellus chilensis* | 12 | 2.51455 | 0 | 0 | 0.0055 | 0.0630 | 37 | N | N |
| *Euplectes orix* | 13 | 1.21085 | 0 | 0 | 0.0068 | 0.0556 | 21 | N | N |
| *Agapornis roseicollis* | 13 | 1.7364 | 0 | 1 | 0.0158 | 0.0158 | 11 | N | N |
| *Psittacula cyanocephala* | 13 | 1.81954 | 0 | 0 | 0.0017 | 0.0354 | 25 | N | Y |
| *Pyrrhura molinae* [2] | 13 | 1.8451 | 0 | 0 | 0.0075 | 0.0098 | 13 | N | N |
| *Acridotheres fuscus* | 13 | 1.91803 | 0 | 0 | 0.0138 | 0.0138 | 14 | N | Y |
| *Aratinga holochlora* | 13 | 2.11394 | 0 | 0 | 0.0067 | 0.0067 | 11 | N | Y |
| *Aratinga wagleri* | 13 | 2.29226 | 0 | 0 | 0.0033 | 0.0401 | 9 | N | Y |
| *Lorius garrulus* [2] | 13 | 2.30103 | 0 | 0 | 0.0054 | 0.0314 | 11 | N | N |
| *Psittacus erithacus* | 13 | 2.39794 | 0 | 0 | 0.0052 | 0.0052 | 12 | N | N |
| *Cacatua goffini* [2] | 13 | 2.54407 | 0 | 0 | 0.0128 | 0.0334 | 10 | N | N |
| *Amazona ochrocephala* [2] | 13 | 2.63347 | 0 | 1 | 0.0119 | 0.0119 | 21 | N | Y |
| *Cacatua galerita* | 13 | 2.95037 | 0 | 0 | 0.0007 | 0.0091 | 38 | N | N |
| *Ara ararauna* | 13 | 3.05115 | 0 | 0 | 0.0003 | 0.0003 | 11 | N | Y |
| *Phasianus colchicus* | 13 | 3.055 | 0 | 1 | 0.0035 | 0.0035 | 45 | N | N |
| *Tadorna ferruginea* | 13 | 3.08991 | 0 | 1 | 0.0384 | 0.0384 | 18 | N | N |
| *Balearica regulorum* | 13 | 3.57657 | 0 | 1 | 0.0992 | 0.0992 | 31 | N | N |
| *cygnus atratus* | 13 | 3.75205 | 0 | 0 | 0.0123 | 0.0123 | 35 | N | N |
| **Invasive species removed from analysis as per Chapter 2.** | | | | | | | | | |
| *Hirundo fulva* | 3 | 1.3096 | 1 | 0 | 0.0042 | 0.0633 | 31 | Y | N |
| *Passer domesticus* | 3 | 1.4425 | 1 | 0 | 0.0077 | 0.0111 | 90 | N | N |
| *Molothrus bonariensis* | 3 | 1.5478 | 1 | 1 | 0.0228 | 0.0228 | 11 | N | Y |
| *Molothrus ater* | 3 | 1.6425 | 1 | 0 | 0.001 | 0.0350 | 75 | N | N |
| *Icterus pectoralis* | 3 | 1.6484 | 1 | 0 | 0.0014 | 0.0409 | 48 | Y | N |
| *Sturnus vulgaris* | 3 | 1.9154 | 1 | 0 | 0.0112 | 0.0112 | 62 | N | N |
| *Crotophaga ani* | 3 | 2.0212 | 1 | 1 | 0.0162 | 0.0162 | 48 | N | N |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Bubulcus ibis* | 3 | 2.5289 | 1 | 0 | 0.0089 | 0.0486 | 43 | N | N |
| *Columba livia* | 3 | 2.5496 | 1 | 0 | 0.0073 | 0.0279 | 196 | Y | N |
| *Branta canadensis canadensis* | 3 | 3.5519 | 1 | 1 | 0.1239 | 0.1239 | 10 | N | N |

[1] Successful and unsuccessfully introduced bird species in south Florida. Data used in analyses includes body mass in grams (Mass), Classification (Status: 3 = successful and 11 - 13 are categories of unsuccessful introduction, "11" species with a strong indication of potential success ), Log10 body mass (Log mass), success of species (Success), whether the species fell into a body mass lump or gap (Gap), distance on a log10 axis to nearest native species (Near), distance on a log10 axis to nearest lump-edge species (Edge), number of years before 1996 of introduction (Years), presence of a native congener (Ncong), and presence of a non-indigenous congener (NIScong). Body mass sources for successful species may be found in Appendix A. All other body mass data was from Dunning 1993, unless otherwise noted. Introduction date was determined from Stevenson and Anderson 1995.

[2] Body mass estimate from Low (1992).

APPENDIX D
AVIFAUNA INTRODUCED INTO SOUTH FLORIDA
WITH AN INADEQUATE PROPAGULE

| Species | Species |
|---|---|
| *Agapornis fischeri* | *Estrilda melpoda* |
| *Agapornis personata* | *Euplectes afer* |
| *Alectoris chukar* | *Geopelia cuneata* |
| *Amandava amandava* | *Icterus icterus* |
| *Amandava subflava* | *Leiothrix lutea* |
| *Amazona barbadensis* | *Lonchura maja* |
| *Amazona farinosa* | *Lonchura maja* |
| *Amazona festiva* | *Lonchura malacca* |
| *Amazona pretrei* | *Lonchura nana* |
| *Anodorhynchus hyacinthinus* | *Musophaga violacea* |
| *Anser fabalis* | *neochen jubatus* |
| *Ara auricollis* | *Nothura maculosa* |
| *Ara macao* | *passer luteus* |
| *Ara militaris* | *Pionus senilis* |
| *Ara nobilis* | *Pitta guajana* |
| *Aratinga aurea* | *Ploceus velatus* |
| *Aratinga chloroptera* | *Poicephalus rueppellii* |
| *Aratinga finschi* | *Psarocolius montezuma* |
| *Aratinga leucopthalmus* | *Psittacula eupatria* |
| *Aratinga pertinax* | *Psittacula roseata* |
| *Bucorvus abyssinicus* | *Ramphastos citrolaemus* |
| *Cacatua alba* | *Ramphastos sulfuratus* |
| *Cacatua moluccensis* | *Ramphastos toco* |
| *Carduelis carduelis* | *Rhyncopsitta terrisi* |
| *Cyanocorax caeruleus* | *Sicalis flaveola* |
| *Cyanocorax yncas* | *Streptopelia chinensis* |
| *Cyanoliseus patagonus* | *Trichoglossus chlorolepidtus* |
| *Eclectus roratus* | *Trichoglossus haematod* |
| *Eolophus roseicapillus* | *Trichoglossus ornatus* |
| *Ephippiorhynchus asiatus* | *Uraeginthus bengalus* |

APPENDIX E
BIRDS OF MEDITERRANEAN-CLIMATE ECOSYSTEMS

## CALIFORNIA[1]

| Latin name | Mass | Gap statistic | Lump |
|---|---|---|---|
| *Calypte costae* | 0.491 | 0.00000 | 1 |
| *Selasphorus sasin* | 0.528 | 0.12521 | 1 |
| *Archilochus alexandri* | 0.531 | 0.00004 | 1 |
| *Calypte anna* | 0.623 | 0.73500 | 1 |
| *Polioptila melanura* | 0.708 | **0.83541** | 2 |
| *Psaltriparus minimus* | 0.724 | 0.08528 | 2 |
| *Polioptila caerulea* | 0.778 | 0.71612 | 2 |
| *Wilsonia pusilla* | 0.839 | **0.85573** | 3 |
| *Dendroicha nigrescens* | 0.922 | **0.97271** | 3 |
| *Certhia americana* | 0.924 | 0.00127 | 3 |
| *Troglodytes troglodytes* | 0.949 | 0.48840 | 3 |
| *Vermivora celata* | 0.954 | 0.01433 | 3 |
| *Dendroica petechia* | 0.978 | 0.44895 | 3 |
| *Carduelis psaltria* | 0.978 | 0.00000 | 3 |
| *Parus rufescens* | 0.987 | 0.08910 | 3 |
| *Thryomanes bewickii* | 0.996 | 0.07268 | 3 |
| *Empidonax difficilis* | 1.000 | 0.01011 | 3 |
| *Empidonax hammondii* | 1.004 | 0.01031 | 3 |
| *Geothlypis trichas* | 1.004 | 0.00000 | 3 |
| *Empidonax oberholseri* | 1.017 | 0.16915 | 3 |
| *Sitta pygmaea* | 1.025 | 0.06154 | 3 |
| *Troglodytes aedon* | 1.037 | 0.17882 | 3 |
| *Spizella breweri* | 1.037 | 0.00000 | 3 |
| *Carduelis lawrencei* | 1.039 | 0.00228 | 3 |
| *Cistothorus palustris* | 1.051 | 0.15893 | 3 |
| *Vireo huttoni* | 1.064 | 0.21922 | 3 |
| *Spizella atrogularis* | 1.076 | 0.16879 | 3 |
| *Spizella passerina* | 1.090 | 0.26086 | 3 |
| *Catherpes mexicanus* | 1.100 | 0.15047 | 3 |
| *Contopus sordidulus* | 1.107 | 0.05785 | 3 |

| | | | |
|---|---|---|---|
| *Vireo vicinior* | 1.107 | 0.00000 | 3 |
| *Carduelis tristis* | 1.111 | 0.00753 | 3 |
| *Empidonax traillii* | 1.127 | 0.34029 | 3 |
| *Amphispiza bilineata* | 1.130 | 0.00796 | 3 |
| *Tachycineta thalassina* | 1.151 | 0.50306 | 3 |
| *Pyrocephalus rubinus* | 1.158 | 0.08715 | 3 |
| *Riparia riparia* | 1.164 | 0.04596 | 3 |
| *Chamaea fasciata* | 1.166 | 0.00008 | 3 |
| *Vireo gilvus* | 1.170 | 0.01755 | 3 |
| *Passerina amoena* | 1.190 | 0.52204 | 3 |
| *Stelgidopteryx serripennis* | 1.201 | 0.20909 | 3 |
| *Salpinctes obsoletus* | 1.217 | 0.37732 | 3 |
| *Vireo solitarius* | 1.220 | 0.00380 | 3 |
| *Passerculus sandwichensis* | 1.230 | 0.18365 | 3 |
| *Ammodramus savannarum* | 1.230 | 0.00000 | 3 |
| *Hyrundo rustica* | 1.233 | 0.00388 | 3 |
| *Parus inornatus* | 1.243 | 0.15483 | 3 |
| *Sayornis nigricans* | 1.271 | 0.76000 | 3 |
| *Aimophila ruficeps* | 1.272 | 0.00010 | 3 |
| *Amphispiza belli* | 1.286 | 0.32632 | 3 |
| *Melospiza melodia* | 1.291 | 0.03546 | 3 |
| *Junco hyemalis* | 1.298 | 0.07694 | 3 |
| *Tachycineta bicolor* | 1.303 | 0.03575 | 3 |
| *Sitta carolinensis* | 1.324 | 0.58675 | 3 |
| *Sayornis saya* | 1.326 | 0.00110 | 3 |
| *Carpodacus mexicanus* | 1.330 | 0.02132 | 3 |
| *Hirundo pyrrhonota* | 1.334 | 0.01076 | 3 |
| *Phainopepla nitens* | 1.380 | **0.95496** | 4 |
| *Icterus cucullatus* | 1.386 | 0.03656 | 4 |
| *Carpodacus purpureus* | 1.396 | 0.19666 | 4 |
| *Icteria virens* | 1.403 | 0.07862 | 4 |
| *Pooecetes gramineus* | 1.410 | 0.05561 | 4 |
| *Picoides pubescens* | 1.431 | 0.61589 | 4 |
| *Myiarchus cinerascens* | 1.435 | 0.00424 | 4 |
| *Zonotrichia leucophrys* | 1.441 | 0.07780 | 4 |
| *Sialia mexicana* | 1.448 | 0.07757 | 4 |
| *Guiraca caerulea* | 1.453 | 0.03582 | 4 |
| *Chondestes grammacus* | 1.462 | 0.13110 | 4 |
| *Sialia currucoides* | 1.471 | 0.13055 | 4 |
| *Columbina passerina* | 1.479 | 0.10187 | 4 |
| *Catharus ustulatus* | 1.489 | 0.15940 | 4 |
| *Eremophila alpestris* | 1.496 | 0.10077 | 4 |

| | | | |
|---|---|---|---|
| *Aeronautes saxatalis* | 1.507 | 0.15774 | 4 |
| *Icterus galbula* | 1.526 | 0.54552 | 4 |
| *Picoides nuttallii* | 1.583 | **0.97667** | 5 |
| *Tyrannus verticalis* | 1.598 | 0.30483 | 5 |
| *Pipilo erythrophthalmus* | 1.610 | 0.23663 | 5 |
| *Micrathene whitneyi* | 1.613 | 0.00349 | 5 |
| *Charadrius alexanrinus* | 1.617 | 0.01768 | 5 |
| *Sterna antillarum* | 1.634 | 0.42403 | 5 |
| *Oreoscoptes montanus* | 1.636 | 0.00086 | 5 |
| *Molothrus ater* | 1.642 | 0.04522 | 5 |
| *Pipilo fuscus* | 1.647 | 0.02901 | 5 |
| *Cypseloides niger* | 1.659 | 0.19463 | 5 |
| *Tyrannus vociferans* | 1.659 | 0.00000 | 5 |
| *Lanius ludovicianus* | 1.676 | 0.37888 | 5 |
| *Mimus polyglottos* | 1.686 | 0.13194 | 5 |
| *Sphyrapicus ruber* | 1.689 | 0.00777 | 5 |
| *Progne subis* | 1.694 | 0.01554 | 5 |
| *Phalaenoptilus nuttallii* | 1.713 | 0.45661 | 5 |
| *Agelaius phoeniceus* | 1.721 | 0.07772 | 5 |
| *Caprimulgus vociferus* | 1.724 | 0.00725 | 5 |
| *Agelaius tricolor* | 1.769 | **0.91256** | 6 |
| *Phalaropus tricolor* | 1.778 | 0.09189 | 6 |
| *Picoides albolarvatus* | 1.786 | 0.09055 | 6 |
| *Chordeiles minor* | 1.789 | 0.00244 | 6 |
| *Euphagus cyanocephalus* | 1.797 | 0.06822 | 6 |
| *Xanthocephalus xanthocephalus* | 1.810 | 0.18613 | 6 |
| *Chlidonias niger* | 1.815 | 0.02116 | 6 |
| *Picoides villosus* | 1.821 | 0.04764 | 6 |
| *Glaucidium gnoma* | 1.829 | 0.04698 | 6 |
| *Porzana carolina* | 1.873 | **0.88086** | 7 |
| *Turdus migratorius* | 1.888 | 0.27091 | 7 |
| *Aphelocoma coerulescens* | 1.904 | 0.26519 | 7 |
| *Melanerpes formicivorus* | 1.906 | 0.00047 | 7 |
| *Rallus limicola* | 1.914 | 0.05453 | 7 |
| *Toxostoma redivivum* | 1.926 | 0.15548 | 7 |
| *Ixobrychus exilis* | 1.936 | 0.08760 | 7 |
| *Charadrius vociferus* | 1.985 | **0.89262** | 8 |
| *Sturnella neglecta* | 2.003 | 0.30693 | 8 |
| *Gymnorhinus cyanocephalus* | 2.013 | 0.07626 | 8 |
| *Falco sparverius* | 2.063 | **0.87234** | 9 |
| *Melanerpes lewis* | 2.064 | 0.00126 | 9 |
| *Zenaida macroura* | 2.076 | 0.08554 | 9 |

| | | | |
|---|---|---|---|
| *Colaptes auratus* | 2.102 | 0.48345 | 9 |
| *Cyanocitta stelleri* | 2.107 | 0.01129 | 9 |
| *Otus kennicottii* | 2.155 | **0.84068** | 10 |
| *Ceryle alcyon* | 2.170 | 0.16884 | 10 |
| *Athene cunicularia* | 2.190 | 0.29745 | 10 |
| *Sterna forsteri* | 2.199 | 0.03349 | 10 |
| *Pica nuttalli* | 2.201 | 0.00261 | 10 |
| *Himantopus mexicanus* | 2.220 | 0.24689 | 10 |
| *Sterna nilotica* | 2.230 | 0.07079 | 10 |
| *Callipepla californica* | 2.238 | 0.02280 | 10 |
| *Dryocopus lineatus* | 2.264 | 0.41588 | 10 |
| *Butorides striatus* | 2.326 | **0.91898** | 11 |
| *Oreortyx pictus* | 2.367 | 0.70619 | 11 |
| *Sterna elegans* | 2.410 | 0.74278 | 11 |
| *Asio otus* | 2.418 | 0.02978 | 11 |
| *Podiceps nigrocollis* | 2.465 | **0.79674** | 12 |
| *Rallus longirostris* | 2.473 | 0.02104 | 12 |
| *Rhynochops niger* | 2.479 | 0.02105 | 12 |
| *Gallinula chloropus* | 2.481 | 0.00022 | 12 |
| *Recurvirostra americana* | 2.500 | 0.23129 | 12 |
| *Elanus caeruleus* | 2.522 | 0.33857 | 12 |
| *Anas crecca* | 2.533 | 0.06568 | 12 |
| *Asio flammeus* | 2.540 | 0.02108 | 12 |
| *Egretta thula* | 2.569 | 0.48461 | 12 |
| *Geococcyx californicus* | 2.575 | 0.01402 | 12 |
| *Anas cyanoptera* | 2.586 | 0.06555 | 12 |
| *Anas discors* | 2.587 | 0.00002 | 12 |
| *Columba fasciata* | 2.593 | 0.02101 | 12 |
| *Circus cyaneus* | 2.639 | **0.77496** | 13 |
| *Accipiter cooperi* | 2.642 | 0.00226 | 13 |
| *Podilymbus podiceps* | 2.645 | 0.00086 | 13 |
| *Corvus brachyrhynchos* | 2.651 | 0.01376 | 13 |
| *Tyto alba* | 2.719 | **0.93036** | 14 |
| *Oxyura jamaicensis* | 2.736 | 0.18084 | 14 |
| *Buteo lineatus* | 2.747 | 0.07486 | 14 |
| *Strix occidentalis* | 2.785 | 0.63551 | 14 |
| *Anas clypeata* | 2.787 | 0.00074 | 14 |
| *Plegadis chihi* | 2.793 | 0.01203 | 14 |
| *Fulica americana* | 2.808 | 0.11615 | 14 |
| *Haematopus bachmani* | 2.812 | 0.00188 | 14 |
| *Sterna caspia* | 2.816 | 0.00709 | 14 |
| *Aix sponsa* | 2.818 | 0.00018 | 14 |

| | | | |
|---|---|---|---|
| *Botaurus lentiginosus* | 2.849 | 0.47462 | 14 |
| *Falco mexicanus* | 2.850 | 0.00002 | 14 |
| *Dendrocygna bicolor* | 2.851 | 0.00002 | 14 |
| *Falco peregrinus* | 2.893 | 0.66654 | 14 |
| *Casmerodius albus* | 2.941 | **0.72784** | 15 |
| *Nycticorax nycticorax* | 2.946 | 0.00278 | 15 |
| *Anas strepera* | 2.964 | 0.14563 | 15 |
| *Buteo swainsoni* | 2.995 | 0.40926 | 15 |
| *Anas acuta* | 3.005 | 0.02733 | 15 |
| *Larus occidentalis* | 3.005 | 0.00000 | 15 |
| *Aythya americana* | 3.019 | 0.08496 | 15 |
| *Anas platyrrhynchos* | 3.034 | 0.08082 | 15 |
| *Buteo jamaicensis* | 3.052 | 0.10039 | 15 |
| *Corvus corax* | 3.079 | 0.27790 | 15 |
| *Bubo virginianus* | 3.117 | 0.41406 | 15 |
| *Branta canadensis* | 3.137 | 0.11410 | 15 |
| *Cathartes aura* | 3.166 | 0.22315 | 15 |
| *Aechmophorus occidentalis* | 3.169 | 0.00042 | 15 |
| *Pandion haliaetus* | 3.172 | 0.00004 | 15 |
| *Phalacrocorax auritus* | 3.224 | 0.50792 | 15 |
| *Ardea herodias* | 3.378 | **0.94103** | 16 |
| *Aqyila chrysaetos* | 3.623 | **0.92765** | 16 |
| *Haliaeetus leucocephalus* | 3.676 | 0.04850 | 16 |
| *Pelecanus erythrorhynchos* | 3.845 | 0.34784 | 16 |
| *Gymnogyps californianus* | 4.004 | 0.14945 | 16 |

**NON-INDIGENOUS SPECIES**

| | |
|---|---|
| *Zosterops japonicus* | 1.000 |
| *Lagonosticta rubricata* | 1.009 |
| *Passer domesticus* | 1.442 |
| *Cardinalis cardinalis* | 1.650 |
| *Brotogeris versicolorus* | 1.781 |
| *Sturna vulgaris* | 1.915 |
| *Psittacula krameri* | 2.066 |
| *Nandayus nenday* | 2.107 |
| *Streptopelia risoria* | 2.134 |
| *Streptopelia chinensis* | 2.201 |
| *Amazona viridigenalis* | 2.468 |
| *Bubulcus ibis* | 2.529 |
| *Columba livia* | 2.550 |
| *Amazona oratrix* | 2.629 |

| | |
|---|---|
| *Alectoris chukar* | 2.762 |
| *Phasianus colchicus* | 3.055 |
| *Pavo cristatus* | 3.622 |
| *Meleagris gallopavo* | 3.764 |

**SAN DIEGO COUNTY**

| | | | |
|---|---|---|---|
| *Archilochus costae* | 0.491 | 0.00000 | 1 |
| *Cynanthus latirostris* | 0.491 | 0.00000 | 1 |
| *Archilochus alexandri* | 0.531 | 0.06442 | 1 |
| *Archilochus anna* | 0.623 | 0.51398 | 1 |
| *Polioptila melanura* | 0.708 | 0.65034 | 1 |
| *Psaltriparius minimus* | 0.724 | 0.03805 | 1 |
| *Polioptila caerulea* | 0.778 | 0.52436 | 1 |
| *Wilsonia pusilla* | 0.839 | **0.71315** | 2 |
| *Dendroica nigrescens* | 0.922 | **0.93195** | 2 |
| *Vireo bellii pusillus* | 0.929 | 0.02195 | 2 |
| *Vermivora celata* | 0.954 | 0.36122 | 2 |
| *Carduelis psaltria* | 0.978 | 0.32628 | 2 |
| *Dendroica petechia* | 0.978 | 0.00000 | 2 |
| *Thryomanes bewickii* | 0.996 | 0.23825 | 2 |
| *Empidonax difficilis* | 1.000 | 0.00538 | 2 |
| *Geothlypis trichas* | 1.004 | 0.00551 | 2 |
| *Parus gambeli baileyae* | 1.033 | 0.53027 | 2 |
| *Troglodytes aedon* | 1.037 | 0.00313 | 2 |
| *Carduelis lawrencei* | 1.039 | 0.00122 | 2 |
| *Cistothorus palustris* | 1.051 | 0.10454 | 2 |
| *Vireo huttoni huttoni* | 1.064 | 0.15011 | 2 |
| *Spizella atrogularis cana* | 1.076 | 0.11274 | 2 |
| *Spizella passerina* | 1.090 | 0.18359 | 2 |
| *Salpinctes mexicanus* | 1.100 | 0.09997 | 2 |
| *Contopus sordidulus* | 1.107 | 0.03544 | 2 |
| *Vireo vicinior* | 1.107 | 0.00000 | 2 |
| *Carduelis tristis* | 1.111 | 0.00422 | 2 |
| *Empidonax traillii* | 1.127 | 0.24900 | 2 |
| *Tachycineta thalassina* | 1.151 | 0.49113 | 2 |
| *Chamaea fasciata* | 1.166 | 0.23788 | 2 |
| *Vireo gilvus* | 1.170 | 0.01015 | 2 |
| *Stelgidopteryx ruficollis* | 1.182 | 0.16528 | 2 |
| *Passerina amoena* | 1.190 | 0.05865 | 2 |
| *Vireo solitarius* | 1.220 | **0.67357** | 3 |

| | | | |
|---|---|---|---|
| *Ammodramus savannarum* | 1.230 | 0.12469 | 3 |
| *Parus inornatus* | 1.243 | 0.17598 | 3 |
| *Sayornis nigricans* | 1.271 | 0.64694 | 3 |
| *Aimophila ruficeps* | 1.272 | 0.00005 | 3 |
| *Aimophila belli* | 1.286 | 0.23467 | 3 |
| *Zonotrichia melodia* | 1.291 | 0.02065 | 3 |
| *Sitta carolinensis* | 1.324 | **0.75910** | 4 |
| *Sayornis saya* | 1.326 | 0.00058 | 4 |
| *Carpodacus mexicanus* | 1.330 | 0.01191 | 4 |
| *Hirundo pyrrhonota* | 1.334 | 0.00584 | 4 |
| *Phainopepla nitens* | 1.380 | **0.90820** | 5 |
| *Icterus cucullatus* | 1.386 | 0.02050 | 5 |
| *Carpodacus purpureus* | 1.396 | 0.12842 | 5 |
| *Icteria virens auricollis* | 1.403 | 0.04639 | 5 |
| *Dendrocopos pubescens* | 1.431 | 0.64431 | 5 |
| *Myiarchus cinerascens* | 1.435 | 0.00214 | 5 |
| *Sialia mexicana* | 1.448 | 0.22741 | 5 |
| *Passerina caerulea* | 1.453 | 0.01936 | 5 |
| *Chondestes grammacus* | 1.462 | 0.07933 | 5 |
| *Pipilo chlorurus* | 1.468 | 0.03001 | 5 |
| *Catharus ustulatus* | 1.489 | 0.41244 | 5 |
| *Eremophila alpestris* | 1.496 | 0.05816 | 5 |
| *Aeronautes saxatalis* | 1.507 | 0.09550 | 5 |
| *Zonotrichia iliaca* | 1.509 | 0.00192 | 5 |
| *Icterus galbula parvus* | 1.526 | 0.31973 | 5 |
| *Dendrocopos nuttallii* | 1.583 | **0.94191** | 6 |
| *Campylorhynchus brunneicapillus* | 1.590 | 0.02447 | 6 |
| *Tyrannus verticalis* | 1.598 | 0.04916 | 6 |
| *Pipilo erythrophthalmus* | 1.610 | 0.14292 | 6 |
| *Pheucticus melanocephalus* | 1.623 | 0.16231 | 6 |
| *Molothrus ater* | 1.642 | 0.32755 | 6 |
| *Pipilo fuscus senicula* | 1.647 | 0.01329 | 6 |
| *Tyrannus vociferans* | 1.659 | 0.10995 | 6 |
| *Lanius ludovicianus* | 1.676 | 0.23864 | 6 |
| *Mimus polyglottos* | 1.686 | 0.06857 | 6 |
| *Progne subis subis* | 1.694 | 0.03909 | 6 |
| *Chordeiles acutipennis* | 1.698 | 0.00642 | 6 |
| *Phalaenoptilus nuttallii* | 1.713 | 0.17797 | 6 |
| *Agelaius phoeniceus* | 1.721 | 0.03617 | 6 |
| *Agelaius tricolor* | 1.769 | **0.82529** | 7 |
| *Euphagus cyanocephalus* | 1.797 | 0.46049 | 7 |
| *Coccyzus americanus* | 1.806 | 0.04826 | 7 |

| | | | |
|---|---|---|---|
| *Xanthocephalus xanthocephalus* | 1.810 | 0.00077 | 7 |
| *Porzana carolina* | 1.873 | **0.89034** | 8 |
| *Aphelocoma coerulescens* | 1.904 | 0.45005 | 8 |
| *Melanerpes formicivorus* | 1.906 | 0.00013 | 8 |
| *Rallus limicola limicola* | 1.914 | 0.01802 | 8 |
| *Toxostoma redivivum* | 1.926 | 0.06080 | 8 |
| *Ixobrychus exilis hesperis* | 1.936 | 0.02995 | 8 |
| *Charadrius vociferus* | 1.985 | **0.67620** | 9 |
| *Sturnella neglecta* | 2.003 | 0.12666 | 9 |
| *Falco sparverius* | 2.063 | **0.72342** | 9 |
| *Zenaida macroura* | 2.076 | 0.04119 | 9 |
| *Colaptes auratus* | 2.102 | 0.20249 | 9 |
| *Cyanocitta stelleri* | 2.107 | 0.00200 | 9 |
| *Otus kennicottii* | 2.155 | 0.50189 | 9 |
| *Athene cunicularia* | 2.190 | 0.28033 | 9 |
| *Callipepla gambelii* | 2.220 | 0.19020 | 9 |
| *Callipepla californica* | 2.238 | 0.05063 | 9 |
| *Ardeola striata anthonyi* | 2.326 | **0.77749** | 10 |
| *Callipepla picta* | 2.367 | 0.26399 | 10 |
| *Asio otus wilsonianus* | 2.418 | 0.37620 | 10 |
| *Elanus leucurus* | 2.522 | **0.81462** | 11 |
| *Egretta ibis ibis* | 2.529 | 0.00117 | 11 |
| *Geocyx californianus* | 2.575 | 0.31220 | 11 |
| *Columba fasciata* | 2.593 | 0.03823 | 11 |
| *Circus cyaneus hudsonius* | 2.639 | 0.30220 | 11 |
| *Accipiter cooperii* | 2.642 | 0.00017 | 11 |
| *Corvus brachyrhynchos* | 2.651 | 0.00384 | 11 |
| *Tyto alba pratincola* | 2.719 | 0.53787 | 11 |
| *Buteo lineatus* | 2.747 | 0.10811 | 11 |
| *Strix occidentalis* | 2.785 | 0.19956 | 11 |
| *Falco mexicanus* | 2.850 | 0.47447 | 11 |
| *Dendrocygna bicolor* | 2.851 | 0.00000 | 11 |
| *Falco peregrinus* | 2.893 | 0.21333 | 11 |
| *Nycticorax nycticorax* | 2.946 | 0.29257 | 11 |
| *Buteo swainsoni* | 2.995 | 0.22583 | 11 |
| *Buteo jamaicensis* | 3.052 | 0.24456 | 11 |
| *Corvus corax clarionensis* | 3.079 | 0.03926 | 11 |
| *Bubo virginianus* | 3.117 | 0.07054 | 11 |
| *Cathartes aura* | 3.166 | 0.10231 | 11 |
| *Aquila chrysaetos* | 3.623 | **0.86536** | 12 |
| *Gymnogyps californicus* | 4.004 | 0.20863 | 12 |

**CHILE**

| | | | |
|---|---|---|---|
| *Sephanoides sephanoides* | 0.716 | 0.00000 | 1 |
| *Anairetes parulus* | 0.771 | 0.19099 | 1 |
| *Tachuris rubrigastra* | 0.857 | 0.52525 | 1 |
| *Pseudocolopteryx flaviventris* | 0.875 | 0.02081 | 1 |
| *Leptasthenura aegithaloides* | 0.954 | **0.59133** | 2 |
| *Cistothorus platensis* | 0.954 | 0.00000 | 2 |
| *Pygochelidon cyanoleuca* | 1.000 | 0.31305 | 2 |
| *Troglodytes aedon* | 1.017 | 0.03630 | 2 |
| *Sylviorthorhynchus desmursii* | 1.037 | 0.06032 | 2 |
| *Scytalopus magellanicus* | 1.085 | 0.39809 | 2 |
| *Aphrastura spinicauda* | 1.086 | 0.00006 | 2 |
| *Lessonia rufa* | 1.130 | 0.38402 | 2 |
| *Phleocryptes melanops* | 1.152 | 0.11067 | 2 |
| *Elaenia albiceps* | 1.201 | 0.50118 | 2 |
| *Sicalis luteola* | 1.204 | 0.00026 | 2 |
| *Carduelis barbata* | 1.220 | 0.06099 | 2 |
| *Phrygilus alaudinus* | 1.255 | 0.32733 | 2 |
| *Anthus correndera* | 1.299 | 0.48460 | 2 |
| *Patagona gigas* | 1.305 | 0.00521 | 2 |
| *Phrygilus gayi* | 1.312 | 0.00529 | 2 |
| *Zonotrichia capensis* | 1.312 | 0.00000 | 2 |
| *Asthenes humicola* | 1.313 | 0.00000 | 2 |
| *Hymenops perspicillata* | 1.380 | **0.79076** | 3 |
| *Geositta cunicularia* | 1.477 | **0.94310** | 3 |
| *Agelaius thilius* | 1.477 | 0.00000 | 3 |
| *Diuca diuca* | 1.491 | 0.07362 | 3 |
| *Cinclodes fuscus* | 1.502 | 0.03434 | 3 |
| *Laterallus jamaicensis* | 1.530 | 0.28410 | 3 |
| *Thraupis bonariensis* | 1.556 | 0.27446 | 3 |
| *Phrygilus fructiceti* | 1.589 | 0.38898 | 3 |
| *Picoides lignarius* | 1.592 | 0.00053 | 3 |
| *Chilia melanura* | 1.602 | 0.02457 | 3 |
| *Phytotoma rara* | 1.602 | 0.00000 | 3 |
| *Charadrius alexandrinus* | 1.617 | 0.09063 | 3 |
| *Caprimulgus longirostris* | 1.635 | 0.13701 | 3 |
| *Thinocorus rumicivorus* | 1.643 | 0.01131 | 3 |
| *Eugralla paradoxa* | 1.643 | 0.00000 | 3 |
| *Pyrope pyrope* | 1.685 | **0.55531** | 4 |
| *Upucerthia dumetaria* | 1.693 | 0.01551 | 4 |

| | | | |
|---|---|---|---|
| *Columbina picui* | 1.699 | 0.00829 | 4 |
| *Scelorchilus albicollis* | 1.705 | 0.00367 | 4 |
| *Charadrius falklandicus* | 1.813 | **0.97300** | 5 |
| *Mimus thenca* | 1.820 | 0.00848 | 5 |
| *Cinclodes nigrofumosus* | 1.824 | 0.00225 | 5 |
| *Glaucidium nanum* | 1.858 | 0.43369 | 5 |
| *Scelorchilus rubecula* | 1.881 | 0.22202 | 5 |
| *Ixobrychus involucris* | 1.948 | **0.84602** | 6 |
| *Curaeus curaeus* | 1.954 | 0.00850 | 6 |
| *Turdus falcklandii* | 1.975 | 0.16802 | 6 |
| *Agriornis livida* | 1.997 | 0.20835 | 6 |
| *Colaptes pitius* | 2.000 | 0.00123 | 6 |
| *Sturnella loyca* | 2.053 | **0.72725** | 7 |
| *Zenaida auriculata* | 2.057 | 0.00123 | 7 |
| *Falco sparverius* | 2.063 | 0.00585 | 7 |
| *Pteroptochos megapodius* | 2.076 | 0.05597 | 7 |
| *Gallinago gallinago* | 2.086 | 0.03983 | 7 |
| *Metriopelia melanoptera* | 2.097 | 0.03281 | 7 |
| *Oreopholus ruficollis* | 2.124 | 0.30869 | 7 |
| *Sterna trudeaui* | 2.185 | **0.80364** | 8 |
| *Athene cunicularia* | 2.189 | 0.00232 | 8 |
| *Himantopus mexicanus* | 2.220 | 0.38369 | 8 |
| *Sterna hirundinacea* | 2.265 | **0.61769** | 9 |
| *Pardirallus sanguinolentus* | 2.294 | 0.35881 | 9 |
| *Rollandia rolland* | 2.395 | **0.96760** | 9 |
| *Cyanoliseus patagonus* | 2.436 | 0.56868 | 9 |
| *Milvago chimango* | 2.471 | 0.47896 | 9 |
| *Larus maculipennis* | 2.505 | 0.43742 | 9 |
| *Vanellus chilensis* | 2.515 | 0.02843 | 9 |
| *Merganetta armata* | 2.519 | 0.00247 | 9 |
| *Elanus leucurus* | 2.522 | 0.00134 | 9 |
| *Falco femoralis* | 2.523 | 0.00001 | 9 |
| *Podiceps occipitalis* | 2.524 | 0.00001 | 9 |
| *Accipiter bicolor* | 2.532 | 0.01723 | 9 |
| *Asio flammeus* | 2.540 | 0.01283 | 9 |
| *Egretta thula* | 2.569 | 0.36327 | 9 |
| *Anas cyanoptera* | 2.586 | 0.12366 | 9 |
| *Anas flavirostris* | 2.597 | 0.03433 | 9 |
| *Circus cinereus* | 2.623 | 0.30031 | 9 |
| *Podilymbus podiceps* | 2.645 | 0.21206 | 9 |
| *Fulica leucoptera* | 2.653 | 0.01618 | 9 |
| *Nothoprocta perdicaria* | 2.661 | 0.01196 | 9 |

| | | | |
|---|---|---|---|
| *Anas platalea* | 2.719 | **0.76887** | 10 |
| *Tyto alba* | 2.719 | 0.00000 | 10 |
| *Heteronetta atricapilla* | 2.726 | 0.01107 | 10 |
| *Oxyura jamaicensis* | 2.736 | 0.02437 | 10 |
| *Oxyura vittata* | 2.748 | 0.04347 | 10 |
| *Anas georgica* | 2.766 | 0.11906 | 10 |
| *Fulica rufifrons* | 2.791 | 0.24037 | 10 |
| *Plegadis chihi* | 2.793 | 0.00047 | 10 |
| *Haematopus palliatus* | 2.801 | 0.00696 | 10 |
| *Falco peregrinus* | 2.893 | **0.92729** | 11 |
| *Phalcoboenus megalopterus* | 2.900 | 0.00758 | 11 |
| *Anas sibilatrix* | 2.918 | 0.09083 | 11 |
| *Parabuteo unicinctus* | 2.926 | 0.00949 | 11 |
| *Casmerodius albus* | 2.941 | 0.06082 | 11 |
| *Nycticorax nycticorax* | 2.946 | 0.00120 | 11 |
| *Polyborus plancus* | 2.951 | 0.00198 | 11 |
| *Larus dominicanus* | 2.954 | 0.00029 | 11 |
| *Anas specularis* | 2.989 | 0.31718 | 11 |
| *Netta peposaca* | 3.000 | 0.01926 | 11 |
| *Phalacrocorax olivaceus* | 3.041 | 0.38186 | 11 |
| *Bubo virginianus* | 3.117 | **0.71677** | 12 |
| *Cathartes aura* | 3.166 | 0.37888 | 12 |
| *Theristicus caudatus* | 3.190 | 0.07826 | 12 |
| *Coragyps atratus* | 3.318 | **0.83322** | 13 |
| *Geranoaetus melanoleucus* | 3.353 | 0.07860 | 13 |
| *Cygnus melancoryphus* | 3.672 | **0.93618** | 13 |

**No body mass estimate available**

*Podiceps major*
*Buteo polyosoma*
*Porphyriops melanops*
*Fulica armillata*
*Nycticryphes semicollaris*
*Columba araucana*
*Enicognathus ferrugineus*
*Enicognathus leptorhynchus*
*Strix rufipes*
*Cinclodes patagonicus*
*Asthenes pyrrholeuca*
*Pygarrhichas albogularis*
*Pteroptochos castaneus*
*Tachycineta leucopyga*

**NON-INDIGENOUS SPECIES**

| | |
|---|---|
| *Passer domesticus* | 1.442 |
| *Molothrus bonariensis* | 1.548 |
| *Callipepla californica* | 2.238 |
| *Bubulcus ibis* | 2.529 |
| *Columba livia* | 2.550 |
| *Phasianus colchicus* | 3.055 |
| *Cairina moschata* | 3.392 |

**SOUTH AFRICA**

| | | | |
|---|---|---|---|
| *Estrilda astrilid* | 0.875 | 0.00000 | 1 |
| *Nectarinia chalybea* | 0.937 | 0.57766 | 1 |
| *Cisticola fulvicapilla* | 0.954 | 0.05969 | 1 |
| *Nectarinia violacea* | 0.964 | 0.01222 | 1 |
| *Prinia maculosa* | 1.000 | 0.35436 | 1 |
| *Cisticola subruficapilla* | 1.021 | 0.14359 | 1 |
| *Sylvietta rufescens* | 1.053 | 0.33903 | 1 |
| *Apalis thoracica* | 1.083 | 0.34538 | 1 |
| *Batis capensis* | 1.107 | 0.24999 | 1 |
| *Cisticola tinniens* | 1.111 | 0.00108 | 1 |
| *Riparia paludicola* | 1.127 | 0.12313 | 1 |
| *Zosterops virens* | 1.127 | 0.00000 | 1 |
| *Serinus canicollis* | 1.140 | 0.07365 | 1 |
| *Saxicola torquata* | 1.185 | **0.69257** | 2 |
| *Parisoma subcaeruleum* | 1.193 | 0.02486 | 2 |
| *Hirundo rustica* | 1.204 | 0.05719 | 2 |
| *Euplectes orix* | 1.211 | 0.01514 | 2 |
| *Serinus flaviventris* | 1.212 | 0.00007 | 2 |
| *Nectarinia famosa* | 1.233 | 0.24837 | 2 |
| *Euplectes capensis* | 1.260 | 0.41522 | 2 |
| *Cercomela sinuata* | 1.270 | 0.03731 | 2 |
| *Hirundo rupestris* | 1.279 | 0.04651 | 2 |
| *Serinus sulphuratus* | 1.283 | 0.00577 | 2 |
| *Parus afer* | 1.297 | 0.10364 | 2 |
| *Calandrella cinerea* | 1.316 | 0.23999 | 2 |
| *Motacilla capensis* | 1.318 | 0.00036 | 2 |
| *Hirundo albigularis* | 1.328 | 0.05926 | 2 |
| *Passer melanurus* | 1.340 | 0.09467 | 2 |
| *Cercomela familiaris* | 1.342 | 0.00037 | 2 |

| | | | |
|---|---|---|---|
| *Emberiza capensis* | 1.350 | 0.02534 | 2 |
| *Anthus novaeseelandiae* | 1.384 | **0.57927** | 3 |
| *Sigelus silens* | 1.408 | 0.38105 | 3 |
| *Serinus albogularis* | 1.413 | 0.00631 | 3 |
| *Hirundo cucullata* | 1.431 | 0.23028 | 3 |
| *Anthus leucophrys* | 1.431 | 0.00000 | 3 |
| *Cossypha caffra* | 1.455 | 0.34460 | 3 |
| *Mirafra apiata* | 1.487 | 0.54328 | 3 |
| *Sphenoeacus afer* | 1.497 | 0.04790 | 3 |
| *Lybius leucomelas* | 1.508 | 0.06744 | 3 |
| *Pycnonotus capensis* | 1.597 | **0.97140** | 4 |
| *Promerops cafer* | 1.606 | 0.03978 | 4 |
| *Oena capensis* | 1.608 | 0.00027 | 4 |
| *Colius colius* | 1.617 | 0.03140 | 4 |
| *Lanius collaris* | 1.618 | 0.00001 | 4 |
| *Ploceus capensis* | 1.627 | 0.03783 | 4 |
| *Apus barbatus* | 1.631 | 0.00264 | 4 |
| *Caprimulgus pectoralis* | 1.674 | **0.64749** | 5 |
| *Macronyx capensis* | 1.677 | 0.00058 | 5 |
| *Lanius ferrugineus* | 1.688 | 0.04666 | 5 |
| *Colius striatus* | 1.708 | 0.19922 | 5 |
| *Colius indicus* | 1.751 | **0.60253** | 6 |
| *Monticola rupestris* | 1.778 | 0.28130 | 6 |
| *Upupa epops* | 1.788 | 0.02758 | 6 |
| *Malaconotus zeylonus* | 1.797 | 0.01732 | 6 |
| *Creatophora cinerea* | 1.826 | 0.28686 | 6 |
| *Turdus olivaceus* | 1.868 | 0.47633 | 6 |
| *Apus melba* | 1.881 | 0.03736 | 6 |
| *Streptopelia senegalensis* | 2.004 | **0.83515** | 7 |
| *Spreo bicolor* | 2.021 | 0.04328 | 7 |
| *Geocolaptes olivaceus* | 2.079 | 0.47421 | 7 |
| *Onychognathus morio* | 2.124 | 0.28491 | 7 |
| *Streptopelia capicola* | 2.152 | 0.09339 | 7 |
| *Vanellus coronatus* | 2.223 | 0.47273 | 7 |
| *Falco tinnunculus* | 2.304 | 0.50898 | 7 |
| *Elanus caeruleus* | 2.522 | **0.95101** | 8 |
| *Bubulcus (=Ardeola) ibis* | 2.529 | 0.00035 | 8 |
| *Columba guinea* | 2.547 | 0.01180 | 8 |
| *Francolinus africanus* | 2.592 | 0.14653 | 8 |
| *Burhinus capensis* | 2.626 | 0.07619 | 8 |
| *Circus ranivorus* | 2.705 | 0.40611 | 8 |
| *Corvus albus* | 2.723 | 0.01286 | 8 |

| | | | |
|---|---|---|---|
| *Francolinus capensis* | 2.814 | 0.48452 | 8 |
| *Afrotis afra* | 2.840 | 0.03162 | 8 |
| *Corvus capensis* | 2.843 | 0.00002 | 8 |
| *Buteo buteo* | 2.942 | 0.48903 | 8 |
| *Corvus albicollis* | 2.954 | 0.00220 | 8 |
| *Ardea melanocephala* | 3.025 | 0.24681 | 8 |
| *Buteo rufofuscus* | 3.066 | 0.05806 | 8 |
| *Sagittarius serpantarius* | 3.557 | **0.93768** | 9 |
| *Aquila verreauxi* | 3.613 | 0.00974 | 9 |
| *Otis denhami* | 3.615 | 0.00000 | 9 |

**No body mass estimate available**

*Serinus leucopterus*
*Serinus tottus*
*Cisticola textrix*
*Erythropygia coryphaea*
*Bradypterus victorini*
*Calendula magnirostris*
*Certhilauda curvirostris*
*Certhilauda albescens*
*Anthoscopus minutus*
*Chaetops frenatus*

**NON-INDIGENOUS SPECIES**

| | | | |
|---|---|---|---|
| *Delichon urbica* | 1.161 | | |
| *Fringilla coelebs* | 1.330 | | |
| *Passer domesticus* | 1.362 | | |
| *Apus horus* | 1.447 | | |
| *Sturnus vulgaris* | 1.915 | | |
| *Cuculus clamosus* | 1.929 | | |
| *Alectoris chukar* | 2.762 | | |
| *Numida meleagris* | 3.114 | | |

**SPAIN**

| | | | |
|---|---|---|---|
| *Aegithalos caudatus* | 0.895 | 0.00000 | 1 |
| *Phylloscopus bonelli* | 0.913 | 0.10038 | 1 |
| *Certhia brachydactyla* | 0.914 | 0.00000 | 1 |
| *Cisticola juncidis* | 0.940 | 0.23649 | 1 |
| *Sylvia cantillans* | 0.964 | 0.22535 | 1 |
| *Troglodytes troglodytes* | 0.973 | 0.02758 | 1 |

| | | | |
|---|---|---|---|
| *Sylvia undata* | 0.973 | 0.00000 | 1 |
| *Parus ater* | 0.987 | 0.07233 | 1 |
| *Sylvia conspicillata* | 1.004 | 0.15423 | 1 |
| *Parus caeurleus* | 1.029 | 0.31077 | 1 |
| *Hippolais pallida* | 1.039 | 0.05023 | 1 |
| *Hippolais polyglotta* | 1.041 | 0.00038 | 1 |
| *Serinus serinus* | 1.077 | 0.59406 | 1 |
| *Parus cristatus* | 1.099 | 0.28957 | 1 |
| *Riparia riparia* | 1.119 | 0.30491 | 1 |
| *Cettia cetti* | 1.125 | 0.02106 | 1 |
| *Sylvia melanocephala* | 1.129 | 0.00158 | 1 |
| *Saxicola torquata* | 1.161 | 0.61561 | 1 |
| *Muscicapa striata* | 1.197 | **0.69460** | 2 |
| *Carduelis carduelis* | 1.210 | 0.13858 | 2 |
| *Phoenicurus ochruros* | 1.211 | 0.00002 | 2 |
| *Oenanthe hispanica* | 1.217 | 0.02732 | 2 |
| *Erithacus rubecula* | 1.223 | 0.01295 | 2 |
| *Motacilla cinerea* | 1.261 | **0.76897** | 3 |
| *Motacilla flava* | 1.268 | 0.03989 | 3 |
| *Parus major* | 1.272 | 0.00229 | 3 |
| *Hirundo rustica* | 1.281 | 0.08073 | 3 |
| *Carduelis cannabina* | 1.290 | 0.06636 | 3 |
| *Delichon urbica* | 1.291 | 0.00002 | 3 |
| *Sylvia atricapilla* | 1.291 | 0.00000 | 3 |
| *Luscinia megarhynchos* | 1.312 | 0.38602 | 3 |
| *Motacilla alba* | 1.322 | 0.09891 | 3 |
| *Sylvia hortensis* | 1.324 | 0.00091 | 3 |
| *Fringilla coelebs* | 1.331 | 0.04150 | 3 |
| *Calandrella brachydactyla* | 1.347 | 0.23667 | 3 |
| *Hirundo daurica* | 1.347 | 0.00000 | 3 |
| *Ptyonprogne rupestris* | 1.364 | 0.25801 | 3 |
| *Emberiza cia* | 1.366 | 0.00238 | 3 |
| *Calandrella rufescens* | 1.377 | 0.08253 | 3 |
| *Cercotrichas galactotes* | 1.387 | 0.11588 | 3 |
| *Oenanthe oenanthe* | 1.389 | 0.00023 | 3 |
| *Emberiza cirlus* | 1.408 | 0.34160 | 3 |
| *Lullula arborea* | 1.417 | 0.05248 | 3 |
| *Carduelis chloris* | 1.418 | 0.00022 | 3 |
| *Anthus campestris* | 1.459 | **0.81251** | 4 |
| *Passer domesticus* | 1.478 | 0.28619 | 4 |
| *Acrocephalus arundinaceus* | 1.479 | 0.00020 | 4 |
| *Lanius senator* | 1.512 | 0.65584 | 4 |

| | | | |
|---|---|---|---|
| *Alcedo atthis* | 1.550 | **0.74849** | 5 |
| *Galerida theklae* | 1.566 | 0.20409 | 5 |
| *Alauda arvensis* | 1.585 | 0.27843 | 5 |
| *Oenanthe leucura* | 1.600 | 0.19607 | 5 |
| *Apus apus* | 1.630 | 0.56377 | 5 |
| *Galerida cristata* | 1.650 | 0.27876 | 5 |
| *Milaria calandra* | 1.694 | **0.78303** | 6 |
| *Merops apiaster* | 1.741 | **0.78720** | 6 |
| *Monticola solitarius* | 1.756 | 0.14717 | 6 |
| *Coccothraustes coccothraustes* | 1.763 | 0.01758 | 6 |
| *Cinclus cinclus* | 1.778 | 0.15971 | 6 |
| *Melanocorypha calandra* | 1.783 | 0.00775 | 6 |
| *Larius excubitor* | 1.802 | 0.22283 | 6 |
| *Turnix sylvatica* | 1.813 | 0.06955 | 6 |
| *Upupa epops* | 1.830 | 0.16768 | 6 |
| *Caprimulgus ruficollis* | 1.836 | 0.01584 | 6 |
| *Oriolus oriolus* | 1.847 | 0.06691 | 6 |
| *Glareola pratincola* | 1.904 | **0.85126** | 7 |
| *Dendrocopos major* | 1.906 | 0.00102 | 7 |
| *Caprimulgus europaeus* | 1.929 | 0.29986 | 7 |
| *Otus scops* | 1.930 | 0.00000 | 7 |
| *Sturnus unicolor* | 1.938 | 0.01923 | 7 |
| *Turdus merula* | 1.967 | 0.45584 | 7 |
| *Coturnix coturnix* | 2.007 | 0.60402 | 7 |
| *Apus (Tachymarptis) melba* | 2.017 | 0.04616 | 7 |
| *Rallus aquaticus* | 2.063 | **0.70339** | 8 |
| *Cuculus canorus* | 2.065 | 0.00031 | 8 |
| *Turdus viscivorus* | 2.071 | 0.00798 | 8 |
| *Tachybaptus ruficollis* | 2.130 | **0.82905** | 9 |
| *Streptopelia turtur* | 2.135 | 0.00279 | 9 |
| *Coracias garrulus* | 2.167 | 0.42511 | 9 |
| *Ixobrychus minutus* | 2.169 | 0.00006 | 9 |
| *Falco naumanni* | 2.182 | 0.07155 | 9 |
| *Clamator glandarius* | 2.186 | 0.00252 | 9 |
| *Athene noctua* | 2.196 | 0.02860 | 9 |
| *Garrulus glandarius* | 2.214 | 0.13595 | 9 |
| *Picus viridis* | 2.244 | 0.36629 | 9 |
| *Accipiter nisus* | 2.310 | **0.82134** | 10 |
| *Falco subbuteo* | 2.324 | 0.07281 | 10 |
| *Falco tinnunculus* | 2.366 | 0.50881 | 10 |
| *Corvus monedula* | 2.376 | 0.01946 | 10 |
| *Pterocles alchata* | 2.376 | 0.00000 | 10 |

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|---|---|---|---|
| *Asio Otus* | 2.423 | 0.56979 | 10 |
| *Tyto alba* | 2.454 | 0.28038 | 10 |
| *Columba livia* | 2.469 | 0.06177 | 10 |
| *Gallinula chloropus* | 2.477 | 0.00667 | 10 |
| *Circus pygargus* | 2.499 | 0.12916 | 10 |
| *Pterocles orientalis* | 2.608 | **0.93272** | 11 |
| *Strix aluco* | 2.663 | 0.54299 | 11 |
| *Burhinus oedicnemus* | 2.665 | 0.00007 | 11 |
| *Alectoris rufa* | 2.679 | 0.03143 | 11 |
| *Columba palumbus* | 2.689 | 0.01227 | 11 |
| *Corvus corone* | 2.691 | 0.00002 | 11 |
| *Podiceps cristatus* | 2.889 | **0.94079** | 12 |
| *Milvus migrans* | 2.918 | 0.13572 | 12 |
| *Hieraaetus pennatus* | 2.925 | 0.00250 | 12 |
| *Buteo buteo* | 2.929 | 0.00011 | 12 |
| *Ardea purpurea* | 2.941 | 0.01340 | 12 |
| *Falco peregrinus* | 2.949 | 0.00321 | 12 |
| *Accipiter gentilis* | 2.967 | 0.03124 | 12 |
| *Milvus milvus* | 3.020 | 0.37507 | 12 |
| *Corvus corax* | 3.054 | 0.04723 | 12 |
| *Circaetus gallicus* | 3.230 | **0.93382** | 13 |
| *Hieraaetus fasciatus* | 3.312 | 0.40970 | 13 |
| *Neophron percnopterus* | 3.320 | 0.00066 | 13 |
| *Bubo bubo* | 3.347 | 0.02798 | 13 |
| *Aquila heliaca* | 3.514 | **0.72254** | 14 |
| *Ciconia ciconia* | 3.538 | 0.00768 | 14 |
| *Aquila chrysaetos* | 3.642 | 0.26968 | 14 |
| *Otis tarda* | 3.862 | 0.54175 | 14 |
| *Gyps fulvus* | 3.870 | 0.00002 | 14 |

**NON-INDIGENOUS SPECIES**

| | |
|---|---|
| *Amandava amandava* | 0.996 |
| *Oxyura jamaicensis* | 2.820 |
| *Anas platyrhynchos* | 3.032 |
| *Phasianus colchicus* | 3.051 |

**TURKEY**

| | | | |
|---|---|---|---|
| *Regulus regulus* | 0.740 | 0.00000 | 1 |
| *Phylloscopus collybita* | 0.886 | **0.95804** | 1 |
| *Aegithalos caudatus* | 0.895 | 0.00977 | 1 |

| | | | |
|---|---|---|---|
| *Phylloscopus bonelli* | 0.913 | 0.10119 | 1 |
| *Certhia brachydactyla* | 0.914 | 0.00001 | 1 |
| *Sylvia cantillans* | 0.964 | **0.68394** | 2 |
| *Troglodytes troglodytes* | 0.973 | 0.03326 | 2 |
| *Parus ater* | 0.987 | 0.07785 | 2 |
| *Parus caeurleus* | 1.029 | **0.69592** | 3 |
| *Hippolais pallida* | 1.039 | 0.05085 | 3 |
| *Serinus serinus* | 1.077 | **0.68637** | 3 |
| *Sylvia curruca* | 1.089 | 0.11264 | 3 |
| *Sitta krueperi* | 1.097 | 0.03093 | 3 |
| *Riparia riparia* | 1.119 | 0.38113 | 3 |
| *Cettia cetti* | 1.125 | 0.03515 | 3 |
| *Sylvia melanocephala* | 1.129 | 0.00285 | 3 |
| *Sylvia rueppelli* | 1.130 | 0.00003 | 3 |
| *Saxicola torquata* | 1.161 | 0.65504 | 3 |
| *Sylvia communis* | 1.185 | 0.47896 | 3 |
| *Muscicapa striata* | 1.197 | 0.15467 | 3 |
| *Carduelis carduelis* | 1.210 | 0.15821 | 3 |
| *Oenanthe hispanica* | 1.217 | 0.06141 | 3 |
| *Erithacus rubecula* | 1.223 | 0.01435 | 3 |
| *Parus lugubris* | 1.236 | 0.18819 | 3 |
| *Hippolais olivetorum* | 1.243 | 0.06418 | 3 |
| *Motacilla flava* | 1.268 | 0.56388 | 3 |
| *Parus major* | 1.272 | 0.00427 | 3 |
| *Hirundo rustica* | 1.281 | 0.08499 | 3 |
| *Carduelis cannabina* | 1.290 | 0.08548 | 3 |
| *Delichon urbica* | 1.291 | 0.00042 | 3 |
| *Dendrocopos minor* | 1.300 | 0.08590 | 3 |
| *Luscinia megarhynchos* | 1.312 | 0.15053 | 3 |
| *Motacilla alba* | 1.322 | 0.12790 | 3 |
| *Emberiza caesia* | 1.324 | 0.00169 | 3 |
| *Sylvia hortensis* | 1.324 | 0.00000 | 3 |
| *Fringilla coelebs* | 1.331 | 0.05135 | 3 |
| *Lanius nubicus* | 1.334 | 0.00168 | 3 |
| *Calandrella brachydactyla* | 1.347 | 0.19829 | 3 |
| *Hirundo daurica* | 1.347 | 0.00000 | 3 |
| *Sitta europaea* | 1.360 | 0.19725 | 3 |
| *Emberiza cia* | 1.366 | 0.03641 | 3 |
| *Emberiza hortulana* | 1.376 | 0.08418 | 3 |
| *Cercotrichas galactotes* | 1.387 | 0.16944 | 3 |
| *Oenanthe oenanthe* | 1.389 | 0.00040 | 3 |
| *Emberiza cirlus* | 1.408 | 0.36728 | 3 |

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|---|---|---|---|
| *Lullula arborea* | 1.417 | 0.08005 | 3 |
| *Carduelis chloris* | 1.418 | 0.00038 | 3 |
| *Sitta neumayer* | 1.440 | 0.43022 | 3 |
| *Passer hispaniolensis* | 1.451 | 0.13397 | 3 |
| *Emberiza melanocephala* | 1.453 | 0.00035 | 3 |
| *Lanius collurio* | 1.453 | 0.00003 | 3 |
| *Anthus campestris* | 1.459 | 0.02101 | 3 |
| *Oenanthe isabellina* | 1.462 | 0.00352 | 3 |
| *Passer domesticus* | 1.478 | 0.24033 | 3 |
| *Lanius senator* | 1.512 | **0.70663** | 4 |
| *Alauda arvensis* | 1.585 | **0.96788** | 4 |
| *Charadrius dubius* | 1.588 | 0.00217 | 4 |
| *Apus apus* | 1.630 | **0.74875** | 5 |
| *Galerida cristata* | 1.650 | 0.24970 | 5 |
| *Milaria calandra* | 1.694 | **0.72771** | 5 |
| *Merops apiaster* | 1.741 | **0.71919** | 6 |
| *Monticola solitarius* | 1.756 | 0.09647 | 6 |
| *Dendrocopos medius* | 1.771 | 0.10443 | 6 |
| *Melanocorypha calandra* | 1.783 | 0.05495 | 6 |
| *Upupa epops* | 1.830 | 0.62999 | 6 |
| *Oriolus oriolus* | 1.847 | 0.11756 | 6 |
| *Dendrocopos syriacus* | 1.885 | 0.44147 | 6 |
| *Sturnus vulgaris* | 1.892 | 0.00819 | 6 |
| *Caprimulgus europaeus* | 1.929 | 0.41316 | 6 |
| *Otus scops* | 1.930 | 0.00000 | 6 |
| *Turdus merula* | 1.967 | 0.40586 | 6 |
| *Coturnix coturnix* | 2.007 | 0.40039 | 6 |
| *Cuculus canorus* | 2.065 | 0.64437 | 6 |
| *Streptopelia turtur* | 2.135 | **0.73919** | 7 |
| *Coracias garrulus* | 2.167 | 0.24706 | 7 |
| *Falco naumanni* | 2.182 | 0.03090 | 7 |
| *Clamator glandarius* | 2.186 | 0.00108 | 7 |
| *Athene noctua* | 2.196 | 0.01044 | 7 |
| *Garrulus glandarius* | 2.214 | 0.05969 | 7 |
| *Picus viridis* | 2.244 | 0.19297 | 7 |
| *Accipiter nisus* | 2.310 | 0.62055 | 7 |
| *Falco subbuteo* | 2.324 | 0.02696 | 7 |
| *Pica pica* | 2.337 | 0.01829 | 7 |
| *Falco tinnunculus* | 2.366 | 0.14714 | 7 |
| *Corvus monedula* | 2.376 | 0.00494 | 7 |
| *Columba livia* | 2.469 | **0.75676** | 8 |
| *Columba oenas* | 2.477 | 0.00171 | 8 |

| | | | |
|---|---|---|---|
| *Gallinula chloropus* | 2.477 | 0.00000 | 8 |
| *Strix aluco* | 2.663 | **0.94477** | 9 |
| *Burhinus oedicnemus* | 2.665 | 0.00002 | 9 |
| *Corvus corone* | 2.691 | 0.03594 | 9 |
| *Alectoris chukar* | 2.715 | 0.02673 | 9 |
| *Hieraaetus pennatus* | 2.925 | **0.87523** | 10 |
| *Corvus corax* | 3.054 | 0.48195 | 10 |
| *Buteo rufinus* | 3.070 | 0.00215 | 10 |
| *Tadorna ferruginea* | 3.087 | 0.00245 | 10 |
| *Circaetus gallicus* | 3.230 | 0.48241 | 10 |
| *Neophron percnopterus* | 3.320 | 0.19672 | 10 |
| *Aquila heliaca* | 3.514 | 0.60763 | 10 |
| *Ciconia ciconia* | 3.538 | 0.00411 | 10 |
| *Aquila chrysaetos* | 3.642 | 0.20469 | 10 |
| *Gypaetus barbatus* | 3.754 | 0.20757 | 10 |
| *Gyps fulvus* | 3.870 | 0.16638 | 10 |
| *Aegypius monachus* | 3.983 | 0.10208 | 10 |

**NON-INDIGENOUS SPECIES**

| | | | |
|---|---|---|---|
| *Phasianus colchicus* | 3.051 | | |
| *Streptopelia decaocto* | 2.173 | | |
| *Anas platyrhynchos* | 3.032 | | |

**SOUTHWESTERN AUSTRALIA**

| | | | |
|---|---|---|---|
| *Smicrornis brevirostris* | 0.708 | 0.00000 | 1 |
| *Gerygone fusca* | 0.783 | 0.84782 | 1 |
| *Malurus leucopterus* | 0.785 | 0.00048 | 1 |
| *Acanthiza inornata* | 0.845 | **0.82738** | 2 |
| *Poephila guttata* | 0.845 | 0.00000 | 2 |
| *Acanthiza uropygialis* | 0.874 | 0.45154 | 2 |
| *Stipiturus malachurus* | 0.879 | 0.00562 | 2 |
| *Acanthiza apicalis* | 0.881 | 0.00027 | 2 |
| *Certhionyx niger* | 0.892 | 0.06254 | 2 |
| *Petroica goodenovii* | 0.903 | 0.08256 | 2 |
| *Rhipidura fuliginosa* | 0.903 | 0.00000 | 2 |
| *Malurus lamberti* | 0.903 | 0.00000 | 2 |
| *Dicaeum hirundinaceum* | 0.903 | 0.00000 | 2 |
| *Acanthiza chrysorrhoa* | 0.944 | **0.76174** | 3 |
| *Pardalotus punctatus* | 0.964 | 0.30127 | 3 |
| *Malurus pulcherrimus* | 0.978 | 0.18373 | 3 |

| | | | |
|---|---|---|---|
| *Petroica multicolor* | 0.982 | 0.01021 | 3 |
| *Malurus splendens* | 1.000 | 0.27661 | 3 |
| *Malurus elegans* | 1.000 | 0.00000 | 3 |
| *Ephthianura tricolor* | 1.024 | 0.51156 | 3 |
| *Acanthorhynchus superciliosus* | 1.033 | 0.08857 | 3 |
| *Sericornis brunneus* | 1.052 | 0.37056 | 3 |
| *Cecropis ariel* | 1.053 | 0.00006 | 3 |
| *Emblema oculata* | 1.070 | 0.29233 | 3 |
| *Daphoenositta chrysoptera* | 1.076 | 0.02537 | 3 |
| *Ephthianura albifrons* | 1.079 | 0.00736 | 3 |
| *Pardalotus striatus* | 1.086 | 0.05837 | 3 |
| *Aphelocephala leucopsis* | 1.101 | 0.27799 | 3 |
| *Sericornis frontalis* | 1.107 | 0.02771 | 3 |
| *Lichmera indistincta* | 1.114 | 0.04355 | 3 |
| *Sericornis cautus* | 1.153 | **0.85807** | 4 |
| *Melithreptus brevirostris* | 1.164 | 0.17511 | 4 |
| *Hirundo neoxena* | 1.167 | 0.00361 | 4 |
| *Melithreptus lunatus* | 1.167 | 0.00000 | 4 |
| *Cheramoeca leucosternum* | 1.170 | 0.00363 | 4 |
| *Cecropis nigricans* | 1.175 | 0.03183 | 4 |
| *Microeca leucophaea* | 1.196 | 0.47341 | 4 |
| *Lichenostomus ornatus* | 1.250 | **0.96492** | 5 |
| *Phylidonyris albifrons* | 1.255 | 0.02038 | 5 |
| *Pachycephala rufiventris* | 1.258 | 0.00406 | 5 |
| *Phylidonyris nigra* | 1.262 | 0.02048 | 5 |
| *Phylidonyris melanops* | 1.267 | 0.02053 | 5 |
| *Lichenostomus cracticus* | 1.292 | 0.63468 | 5 |
| *Lichenostomus penicillatus* | 1.297 | 0.02075 | 5 |
| *Phylidonyris novaehollandiae* | 1.301 | 0.01045 | 5 |
| *Sericornis fuliginosus* | 1.319 | 0.46154 | 5 |
| *Melanodryas cucullata* | 1.326 | 0.05407 | 5 |
| *Eopsaltria griseogularis* | 1.336 | 0.16020 | 5 |
| *Amytornis textilis* | 1.356 | 0.49196 | 5 |
| *Chrysococcyx basalis* | 1.358 | 0.00106 | 5 |
| *Lichenostomus leucotis* | 1.364 | 0.03496 | 5 |
| *Myiagra inquieta* | 1.380 | 0.35794 | 5 |
| *Anthus novaeseelandiae* | 1.384 | 0.01018 | 5 |
| *Lichenostomus virescens* | 1.391 | 0.05269 | 5 |
| *Chrysococcyx lucidus* | 1.394 | 0.01009 | 5 |
| *Cinclorhamphus mathewsi* | 1.398 | 0.01006 | 5 |
| *Certhionyx variegatus* | 1.414 | 0.35281 | 5 |
| *Lalage sueurii* | 1.415 | 0.00010 | 5 |

| | | | |
|---|---|---|---|
| *Rhipidura leucophrys* | 1.442 | 0.69174 | 5 |
| *Cinclorhamphus cruralis* | 1.447 | 0.01900 | 5 |
| *Falcunculus frontatus* | 1.456 | 0.12085 | 5 |
| *Chrysococcyx osculans* | 1.458 | 0.00095 | 5 |
| *Merops ornatus* | 1.459 | 0.00009 | 5 |
| *Melopsittacus undulatus* | 1.462 | 0.00366 | 5 |
| *Pachycephala inornata* | 1.515 | **0.95036** | 6 |
| *Pachycephala pectoralis* | 1.515 | 0.00000 | 6 |
| *Climacteris rufa* | 1.526 | 0.19613 | 6 |
| *Pomatostomus superciliosus* | 1.544 | 0.34879 | 6 |
| *Artamus cinereus* | 1.544 | 0.00000 | 6 |
| *Artamus personatus* | 1.549 | 0.02754 | 6 |
| *Geopelia cuneata* | 1.550 | 0.00007 | 6 |
| *Drymodes brunneopygia* | 1.568 | 0.37049 | 6 |
| *Artamus cyanopterus* | 1.602 | **0.76676** | 7 |
| *Turnix velox* | 1.613 | 0.11972 | 7 |
| *Halcyon sancta* | 1.620 | 0.05323 | 7 |
| *Neophema elegans* | 1.633 | 0.19460 | 7 |
| *Glossopsitta porphyrocephala* | 1.641 | 0.05084 | 7 |
| *Acanthagenys rufogularis* | 1.643 | 0.00062 | 7 |
| *Cuculus pyrrhophanus* | 1.679 | **0.76240** | 8 |
| *Aegotheles cristatus* | 1.699 | 0.36737 | 8 |
| *Halcyon pyrrhopygia* | 1.719 | 0.35698 | 8 |
| *Psephotus varius* | 1.778 | **0.93575** | 9 |
| *Oreoica gutturalis* | 1.792 | 0.16722 | 9 |
| *Platycercus icterotis* | 1.801 | 0.04726 | 9 |
| *Manorina flavigula* | 1.829 | 0.51848 | 9 |
| *Cinclosoma castanotum* | 1.865 | 0.65589 | 9 |
| *Anthochaera chrysoptera* | 1.871 | 0.01173 | 9 |
| *Colluricincla harmonica* | 1.879 | 0.02751 | 9 |
| *Cuculus pallidus* | 1.934 | **0.86016** | 10 |
| *Turnix varia* | 1.944 | 0.05662 | 10 |
| *Caprimulgus guttatus* | 1.945 | 0.00002 | 10 |
| *Grallina cyanoleuca* | 1.949 | 0.00517 | 10 |
| *Nymphicus hollandicus* | 1.954 | 0.00510 | 10 |
| *Cracticus torquatus* | 1.966 | 0.06753 | 10 |
| *Peltohyas australis* | 1.966 | 0.00000 | 10 |
| *Coracina novaehollandiae* | 1.970 | 0.00233 | 10 |
| *Coturnix australis* | 1.974 | 0.00230 | 10 |
| *Polytelis anthopeplus* | 2.057 | **0.95364** | 11 |
| *Anthochaera carunculata* | 2.097 | 0.58416 | 11 |
| *Purpureicephalus spurius* | 2.107 | 0.03828 | 11 |

| | | | |
|---|---|---|---|
| *Barnardius zonarius* | 2.125 | 0.16309 | 11 |
| *Coracina maxima* | 2.126 | 0.00000 | 11 |
| *Falco cenchroides* | 2.193 | **0.85295** | 12 |
| *Cracticus nigrogularis* | 2.193 | 0.00000 | 12 |
| *Ninox novaeseelandiae* | 2.241 | 0.62910 | 12 |
| *Accipiter cirrhocephalus* | 2.255 | 0.07820 | 12 |
| *Ocyphaps lophotes* | 2.264 | 0.01517 | 12 |
| *Vanellus tricolor* | 2.265 | 0.00001 | 12 |
| *Phaps elegans* | 2.301 | 0.42180 | 12 |
| *Elanus notatus* | 2.398 | **0.93644** | 13 |
| *Falco longipennis* | 2.403 | 0.00339 | 13 |
| *Phaps chalcoptera* | 2.491 | **0.90208** | 13 |
| *Cacatua leadbeateri* | 2.491 | 0.00000 | 13 |
| *Gymnorhina tibicen* | 2.497 | 0.00317 | 13 |
| *Cacatua roseicapilla* | 2.505 | 0.01168 | 13 |
| *Podargus strigoides* | 2.544 | 0.42244 | 13 |
| *Circus assimilis* | 2.623 | **0.84858** | 14 |
| *Ninox connivens* | 2.665 | 0.45208 | 14 |
| *Lophoictinia isura* | 2.700 | 0.33976 | 14 |
| *Accipiter fasciatus* | 2.708 | 0.01000 | 14 |
| *Tyto alba* | 2.719 | 0.02381 | 14 |
| *Cacatua sanguinea* | 2.720 | 0.00001 | 14 |
| *Falco berigora* | 2.740 | 0.10422 | 14 |
| *Ardea novaehollandiae* | 2.742 | 0.00001 | 14 |
| *Tyto novaehollandiae* | 2.785 | 0.44486 | 14 |
| *Calyptorhynchus magnificus* | 2.796 | 0.02055 | 14 |
| *Ardea pacifica* | 2.813 | 0.06227 | 14 |
| *Corvus coronoides* | 2.829 | 0.05140 | 14 |
| *Burhinus magnirostris* | 2.836 | 0.00328 | 14 |
| *Cacatua tenuirostris* | 2.869 | 0.24825 | 14 |
| *Falco peregrinus* | 2.893 | 0.11449 | 14 |
| *Haliastur sphenurus* | 2.903 | 0.01102 | 14 |
| *Calyptorhynchus funereus* | 2.904 | 0.00000 | 14 |
| *Hieraaetus morphnoides* | 2.924 | 0.06691 | 14 |
| *Chenonetta jubata* | 2.940 | 0.03507 | 14 |
| *Tadorna tadornoides* | 3.111 | **0.95455** | 15 |
| *Threskiornis spinicollis* | 3.255 | 0.74926 | 15 |
| *Leipoa ocellata* | 3.273 | 0.00367 | 15 |
| *Aquila audax* | 3.544 | 0.74377 | 16 |
| *Ardeotis australis* | 3.799 | 0.26364 | 16 |
| *Dromaius novaehollandiae* | 4.494 | 0.33955 | 16 |

**No body mass estimate available**

*Strepera versicolor*
*Pardalotus xanthopygus*

**NON-INDIGENOUS SPECIES**

| | |
|---|---|
| *Streptopelia senegalensis* | 2.004 |
| *Coturnix pectoralis* | 2.019 |
| *Dacelo gigas* | 2.520 |
| *Ardeola ibis* | 2.529 |
| *Columba livia* | 2.550 |
| *Egretta alba* | 2.924 |
| *Cacatua galerita* | 2.950 |
| *Threskiornis molucca* | 3.255 |
| *Cygnus olor* | 4.031 |

**SOUTHCENTRAL AUSTRALIA**

| | | | |
|---|---|---|---|
| *Smicrornis brevirostris* | 0.708 | 0.00000 | 1 |
| *Acanthiza nana* | 0.771 | 0.62607 | 1 |
| *Acanthiza uropygialis* | 0.874 | **0.94617** | 2 |
| *Acanthiza reguloides* | 0.875 | 0.00000 | 2 |
| *Acanthiza apicalis* | 0.881 | 0.00757 | 2 |
| *Certhionyx niger* | 0.892 | 0.03158 | 2 |
| *Petroica goodenovii* | 0.903 | 0.04256 | 2 |
| *Rhipidura fuliginosa* | 0.903 | 0.00000 | 2 |
| *Malurus lamberti* | 0.903 | 0.00000 | 2 |
| *Dicaeum hirundinaceum* | 0.903 | 0.00000 | 2 |
| *Acanthiza chrysorrhoa* | 0.944 | 0.59790 | 2 |
| *Pardalotus punctatus* | 0.964 | 0.18254 | 2 |
| *Petroica multicolor* | 0.982 | 0.19315 | 2 |
| *Malurus splendens* | 1.000 | 0.16359 | 2 |
| *Ephthianura tricolor* | 1.024 | 0.34400 | 2 |
| *Sericornis brunneus* | 1.052 | 0.45051 | 2 |
| *Cecropis ariel* | 1.053 | 0.00003 | 2 |
| *Daphoenositta chrysoptera* | 1.076 | 0.31133 | 2 |
| *Pardalotus striatus* | 1.086 | 0.08265 | 2 |
| *Aphelocephala leucopsis* | 1.101 | 0.16521 | 2 |
| *Sericornis frontalis* | 1.107 | 0.01242 | 2 |
| *Poephila guttata* | 1.110 | 0.00131 | 2 |
| *Zosterops lateralis* | 1.111 | 0.00000 | 2 |
| *Sericornis cautus* | 1.153 | **0.77401** | 3 |

| | | | |
|---|---|---|---|
| *Melithreptus brevirostris* | 1.164 | 0.09857 | 3 |
| *Hirundo neoxena* | 1.167 | 0.00154 | 3 |
| *Cheramoeca leucosternum* | 1.170 | 0.00156 | 3 |
| *Cecropis nigricans* | 1.175 | 0.01493 | 3 |
| *Microeca leucophaea* | 1.196 | 0.32207 | 3 |
| *Amytornis striatus* | 1.212 | 0.25066 | 3 |
| *Lichenostomus ornatus* | 1.250 | **0.74880** | 4 |
| *Phylidonyris albifrons* | 1.255 | 0.00993 | 4 |
| *Pachycephala rufiventris* | 1.258 | 0.00188 | 4 |
| *Lichenostomus plumulus* | 1.260 | 0.00048 | 4 |
| *Phylidonyris melanops* | 1.267 | 0.04113 | 4 |
| *Lichenostomus cracticus* | 1.292 | 0.48491 | 4 |
| *Lichenostomus penicillatus* | 1.297 | 0.01056 | 4 |
| *Phylidonyris novaehollandiae* | 1.301 | 0.01062 | 4 |
| *Melanodryas cucullata* | 1.326 | 0.49394 | 4 |
| *Chrysococcyx basalis* | 1.358 | 0.67809 | 4 |
| *Lichenostomus leucotis* | 1.364 | 0.01978 | 4 |
| *Myiagra inquieta* | 1.380 | 0.25777 | 4 |
| *Lichenostomus virescens* | 1.391 | 0.10369 | 4 |
| *Chrysococcyx lucidus* | 1.394 | 0.00564 | 4 |
| *Cinclorhamphus mathewsi* | 1.398 | 0.00565 | 4 |
| *Certhionyx variegatus* | 1.414 | 0.26034 | 4 |
| *Lalage sueurii* | 1.415 | 0.00005 | 4 |
| *Rhipidura leucophrys* | 1.442 | 0.58260 | 4 |
| *Chrysococcyx osculans* | 1.458 | 0.26161 | 4 |
| *Merops ornatus* | 1.459 | 0.00005 | 4 |
| *Melopsittacus undulatus* | 1.462 | 0.00222 | 4 |
| *Pachycephala inornata* | 1.515 | **0.91737** | 5 |
| *Pachycephala pectoralis* | 1.515 | 0.00000 | 5 |
| *Pomatostomus superciliosus* | 1.544 | 0.62310 | 5 |
| *Artamus cinereus* | 1.544 | 0.00000 | 5 |
| *Artamus personatus* | 1.549 | 0.01979 | 5 |
| *Geopelia cuneata* | 1.550 | 0.00005 | 5 |
| *Drymodes brunneopygia* | 1.568 | 0.31125 | 5 |
| *Climacteris picumnus* | 1.568 | 0.00000 | 5 |
| *Artamus superciliosus* | 1.602 | **0.71103** | 6 |
| *Artamus cyanopterus* | 1.602 | 0.00000 | 6 |
| *Turnix velox* | 1.613 | 0.09843 | 6 |
| *Halcyon sancta* | 1.620 | 0.04288 | 6 |
| *Neophema elegans* | 1.633 | 0.16674 | 6 |
| *Glossopsitta porphyrocephala* | 1.641 | 0.04194 | 6 |
| *Acanthagenys rufogularis* | 1.643 | 0.00049 | 6 |

| | | | |
|---|---|---|---|
| *Neophema chrysostoma* | 1.653 | 0.09479 | 6 |
| *Apus pacificus* | 1.656 | 0.00190 | 6 |
| *Cacomantis pyrrhophanus* | 1.679 | 0.42476 | 6 |
| *Aegotheles cristatus* | 1.699 | 0.33928 | 6 |
| *Halcyon pyrrhopygia* | 1.719 | 0.33352 | 6 |
| *Geopelia striata* | 1.748 | 0.57004 | 6 |
| *Pomatostomus ruficeps* | 1.748 | 0.00000 | 6 |
| *Psephotus varius* | 1.778 | 0.57928 | 6 |
| *Oreoica gutturalis* | 1.792 | 0.16156 | 6 |
| *Psephotus haematonotus* | 1.813 | 0.30247 | 6 |
| *Manorina flavigula* | 1.829 | 0.22266 | 6 |
| *Cinclosoma castanotum* | 1.865 | 0.65505 | 6 |
| *Colluricincla harmonica* | 1.879 | 0.12092 | 6 |
| *Glossopsitta concinna* | 1.880 | 0.00003 | 6 |
| *Northiella haematogaster* | 1.903 | 0.36238 | 6 |
| *Cuculus pallidus* | 1.934 | 0.50338 | 6 |
| *Turnix varia* | 1.944 | 0.05844 | 6 |
| *Caprimulgus guttatus* | 1.945 | 0.00002 | 6 |
| *Nymphicus hollandicus* | 1.947 | 0.00025 | 6 |
| *Grallina cyanoleuca* | 1.949 | 0.00098 | 6 |
| *Cracticus torquatus* | 1.966 | 0.15924 | 6 |
| *Coracina novaehollandiae* | 1.970 | 0.00244 | 6 |
| *Barnardius barnardi* | 2.072 | **0.98022** | 7 |
| *Hirundapus caudacutus* | 2.079 | 0.01672 | 7 |
| *Trichoglossus haematodus* | 2.086 | 0.01084 | 7 |
| *Anthochaera carunculata* | 2.097 | 0.04076 | 7 |
| *Coracina maxima* | 2.126 | 0.37771 | 7 |
| *Falco cenchroides* | 2.193 | **0.85631** | 8 |
| *Ninox novaeseelandiae* | 2.241 | 0.62860 | 8 |
| *Accipiter cirrhocephalus* | 2.255 | 0.07684 | 8 |
| *Ocyphaps lophotes* | 2.264 | 0.01472 | 8 |
| *Phaps elegans* | 2.301 | 0.42856 | 8 |
| *Elanus notatus* | 2.398 | **0.92724** | 9 |
| *Falco longipennis* | 2.403 | 0.00280 | 9 |
| *Phaps chalcoptera* | 2.491 | **0.87281** | 9 |
| *Gymnorhina tibicen* | 2.497 | 0.00223 | 9 |
| *Cacatua roseicapilla* | 2.512 | 0.04582 | 9 |
| *Podargus strigoides* | 2.544 | 0.25024 | 9 |
| *Corcorax melanorhamphos* | 2.561 | 0.05709 | 9 |
| *Corvus bennetti* | 2.581 | 0.08178 | 9 |
| *Circus assimilis* | 2.623 | 0.35486 | 9 |
| *Calyptorhynchus lathami* | 2.633 | 0.01141 | 9 |

| | | | |
|---|---|---|---|
| *Accipiter fasciatus* | 2.708 | **0.69469** | 10 |
| *Tyto alba* | 2.719 | 0.01178 | 10 |
| *Cacatua sanguinea* | 2.720 | 0.00000 | 10 |
| *Falco berigora* | 2.740 | 0.05731 | 10 |
| *Corvus mellori* | 2.754 | 0.01712 | 10 |
| *Tyto novaehollandiae* | 2.785 | 0.15412 | 10 |
| *Corvus coronoides* | 2.829 | 0.28385 | 10 |
| *Burhinus magnirostris* | 2.836 | 0.00132 | 10 |
| *Falco subniger* | 2.895 | 0.40714 | 10 |
| *Haliastur sphenurus* | 2.903 | 0.00153 | 10 |
| *Calyptorhynchus funereus* | 2.904 | 0.00000 | 10 |
| *Milvus migrans* | 2.918 | 0.00911 | 10 |
| *Hieraaetus morphnoides* | 2.924 | 0.00088 | 10 |
| *Leipoa ocellata* | 3.273 | **0.98647** | 11 |
| *Aquila audax* | 3.544 | 0.64166 | 11 |
| *Dromaius novaehollandiae* | 4.494 | 0.54362 | 11 |

**No body mass estimate available**

*Sericornus pyrrhopygius*
*Plectorhyncha lanceolata*
*Pardalotus xanthopygus*
*Emblema guttata*
*Struthidea cinerea*
*Strepera versicolor*

[1] Data is arranged by ecosystem, and includes species' latin binomial, log body mass (Mass), gap statistic, and lump membership. All body masses are from Dunning (1993), except for Spain and Turkey, which are from Cramp (1978, 1983a, 1983b, 1984, 1988, 1992, 1993, 1994a, and 1994b).

APPENDIX F
MAMMALS OF MEDITERRANEAN-CLIMATE ECOSYSTEMS

## CALIFORNIA[1]

| Common name | Latin name | Mass | Gap statistic | Lump |
|---|---|---|---|---|
| Ornate shrew | *Sorex ornatus* | 0.6977 | 0 | 1 |
| Vagrant shrew | *Sorex vagrans* | 0.7071 | 5.859E-06 | 1 |
| Harvest mouse | *Reithrodontomys megalotis* | 1.0492 | 0.49929496 | 1 |
| Deer mouse | *Peromyscus maniculatus* | 1.2989 | **0.51234905** | 2 |
| Brush mouse | *Peromyscus boylii* | 1.3294 | 0.00425762 | 2 |
| Pinyon mouse | *Peromyscus truei* | 1.4265 | 0.14119739 | 2 |
| California mouse | *Peromyscus californicus* | 1.6561 | **0.68297407** | 3 |
| Obscure chipmunk | *Tamias obscurus* | 1.7482 | 0.20791874 | 3 |
| Heermann kangaroo rat | *Dipodomys heermanni* | 1.8573 | 0.30653928 | 3 |
| Merriam's chipmunk | *Tamias merriami* | 1.8751 | 0.00252218 | 3 |
| Santa Cruz kangaroo rat | *Dipodomys venustus* | 1.9289 | 0.07147513 | 3 |
| Big-eared kangaroo rat | *Dipodomys elephantinus* | 1.9304 | 2.07E-07 | 3 |
| Botta pocket gopher | *Thomomys bottae* | 2.0492 | 0.36877812 | 3 |
| Desert wood rat | *Neotoma lepida* | 2.1644 | 0.33976801 | 3 |
| Long-tailed weasel | *Mustela frenata* | 2.1673 | 1.894E-06 | 3 |
| Cactus mouse | *Peromyscus eremicus* | 2.2765 | 0.28433037 | 3 |
| Dusky-footed woodrat | *Neotoma fuscipes* | 2.281 | 0.00001688 | 3 |
| California ground squirrel | *Spermophilus beecheyi* | 2.781 | **0.96651709** | 4 |
| Brush Rabbit | *Sylvilagus bachmani* | 2.7853 | 0.00000716 | 4 |
| Audubon cottontail | *Sylvilagus auduboni* | 2.8785 | 0.11267027 | 4 |
| Spotted skunk | *Spilogale gracilis* | 2.8876 | 6.7917E-05 | 4 |
| Ringtail | *Bassaricus astutus* | 3.0529 | 0.32325844 | 4 |
| Striped skunk | *Mephitis mephitis* | 3.2529 | 0.39779723 | 4 |
| Gray fox | *Urocyon cinereoargenteus* | 3.5478 | **0.59163942** | 5 |
| Raccoon | *Procyon lotor psora* | 3.5569 | 4.5319E-05 | 5 |
| Badger | *Taxidea taxus* | 3.8567 | **0.52318831** | 5 |
| Bobcat | *Lynx rufus* | 3.8887 | 0.00130635 | 5 |
| Coyote | *Canis latrans* | 4.1021 | 0.23757954 | 5 |
| Mule deer | *Odocoileus hemionus* | 4.6352 | **0.67689184** | 6 |

| | | | | |
|---|---|---|---|---|
| Cougar | *Felis concolor* | 4.7543 | 0.03227654 | 6 |
| Jaguar | *Felis onca* | 5.0607 | 0.26908978 | 6 |
| Grizzly bear | *Ursos arctos* | 5.1896 | 0.02385989 | 6 |

**Body mass estimate not available**

| | | | | |
|---|---|---|---|---|
| California pocket mouse | *Perognathus californicus* | | | |

**NON-INDIGENOUS SPECIES:**

| | | | | |
|---|---|---|---|---|
| Common opossum | *Didelphis virginianus* | 3.301 | | |
| Wild hog | *Sus scrofa* | 4.624 | | |

**CHILE**

| | | | | |
|---|---|---|---|---|
| Not available | *Marmosa elegans* | 1.4814 | 0 | 1 |
| Not available | *Oryzomys longicaudatus* | 1.5599 | 0.05647732 | 1 |
| Not available | *Akodon olivaceus* | 1.6395 | 0.0698981 | 1 |
| Not available | *Phyllotis darwini* | 1.7889 | **0.31906289** | 2 |
| Not available | *Akodon longipilis* | 1.7959 | 0.00004566 | 2 |
| Not available | *Chelemys macronyx* | 1.8651 | 0.07022734 | 2 |
| Not available | *Euneonys mordax* | 1.9138 | 0.02793766 | 2 |
| Not available | *Octodon bridgesi* | 1.9661 | 0.03540278 | 2 |
| Not available | *Spalacopus cyanus* | 2.0111 | 0.02346644 | 2 |
| Not available | *Aconaemys fuscus* | 2.0903 | 0.10726527 | 2 |
| Not available | *Ctenomys maulinus* | 2.2148 | 0.2728525 | 2 |
| Not available | *Octodon degus* | 2.2641 | 0.02924965 | 2 |
| Not available | *Abrocoma bennetti* | 2.3634 | 0.16076486 | 2 |
| Not available | *Octodon lunatus* | 2.3674 | 4.227E-06 | 2 |
| Not available | *Lagidium viscacia* | 3.1875 | **0.99059769** | 3 |
| Not available | *Galictis gula* | 3.1987 | 0.00013271 | 3 |
| Not available | *Conepatus chinga* | 3.2753 | 0.05554247 | 3 |
| Not available | *Felis Guigna* | 3.3483 | 0.04849784 | 3 |
| Not available | *Felis Colocolo* | 3.4698 | 0.16428676 | 3 |
| Not available | *Myocaster coypus* | 3.5792 | 0.12681176 | 3 |
| Not available | *Dusicyon griseus* | 3.601 | 0.00092599 | 3 |
| Not available | *Lutra felina* | 3.6532 | 0.0159482 | 3 |
| Not available | *Dusicyon culpaeus* | 3.8675 | 0.39085343 | 3 |
| Pudu | *Pudu puda* | 3.989 | 0.10961002 | 3 |
| Not available | *Felis concolor* | 4.549 | **0.78817259** | 4 |
| Not available | *Hippocamelus bisulcus* | 4.8451 | 0.19472369 | 4 |
| Guanaco | *Lama guanicoe* | 5.0792 | 0.06335742 | 4 |

**Body mass estimates not available**

| | | | | |
|---|---|---|---|---|
| Not available | *Lutra provocax* | | | |
| Not available | *Notiomys megalonyx* | | | |

**NON-INDIGENOUS SPECIES**

| | | | | |
|---|---|---|---|---|
| House mouse | *Mus musculus* | 1.2304 | | |
| Black rat | *Rattus rattus* | 2.3284 | | |
| Norway rat | *Rattus norvegicus* | 2.3838 | | |
| Muskrat | *Ondatra zibethica* | 3.0086 | | |
| Mink | *Mustela vison* | 3.1673 | | |
| European rabbit | *Oryctolagus cuniculus* | 3.1959 | | |
| Not available | *Lepus capensis* | 3.301 | | |
| Feral cat | *Felis catus* | 3.5911 | | |
| fallow deer | *Dama dama* | 4.6857 | | |
| Wild hog | *Sus scrofa* | 4.7404 | | |
| red deer | *Cervus elaphus* | 5.1875 | | |

**TURKEY**

| | | | | |
|---|---|---|---|---|
| Not available | *Suncus etruscus* | 0.3522 | 0 | 1 |
| Not available | *Sorex minutus* | 0.4771 | 0.18775036 | 1 |
| Not available | *Crocidura suaveolens* | 0.8254 | **0.900389** | 1 |
| Not available | *Crocidura leucodon* | 0.8921 | 0.12658792 | 1 |
| Not available | *Gerbillus henleyi* | 1.0682 | **0.70234544** | 2 |
| Not available | *Neomys anomalus* | 1.1335 | 0.18367548 | 2 |
| Not available | *Apodemus microps* | 1.233 | 0.40670838 | 2 |
| Not available | *Microtus arvalis* | 1.2617 | 0.02776232 | 2 |
| Not available | *Mus domesticus* | 1.2833 | 0.01376664 | 2 |
| Not available | *Gerbillus dasyurus* | 1.3118 | 0.02609861 | 2 |
| Not available | *Gerbillus pyramidum* | 1.3222 | 0.00153782 | 2 |
| Not available | *Muscardinus avellanarius* | 1.3444 | 0.0149461 | 2 |
| Not available | *Apodemus sylvaticus* | 1.3444 | 0 | 2 |
| Not available | *Apodemus flavicollis* | 1.3541 | 0.00068896 | 2 |
| Not available | *Dryomys nitedula* | 1.4082 | 0.16573051 | 2 |
| Not available | *Gerbillus allenbyi* | 1.4393 | 0.04320658 | 2 |
| Not available | *Talpa caeca* | 1.5051 | 0.24559172 | 2 |
| Not available | *Allactaga euphratica* | 1.5551 | 0.14918463 | 2 |
| Not available | *Microtus nivalis* | 1.5911 | 0.07149298 | 2 |
| Not available | *Cricetulus migratorius* | 1.5977 | 0.00028147 | 2 |
| Not available | *Acomys cahirinus* | 1.6232 | 0.03030443 | 2 |

| | | | | |
|---|---|---|---|---|
| Not available | *Apodemus mystacinus* | 1.659 | 0.07393687 | 2 |
| Not available | *Microtus guentheri* | 1.7114 | 0.17636398 | 2 |
| Not available | *Jaculus jaculus* | 1.8722 | **0.81917226** | 3 |
| Not available | *Eliomys quercinus* | 1.98 | **0.5859386** | 3 |
| Not available | *Meriones tristami* | 2.0212 | 0.10523543 | 3 |
| Not available | *Meriones crassus* | 2.0212 | 0 | 3 |
| Not available | *Mesocricetus auratus* | 2.0755 | 0.18674627 | 3 |
| Not available | *Rattus rattus* | 2.0917 | 0.0072372 | 3 |
| Not available | *Arvicola terrestris* | 2.1139 | 0.01982638 | 3 |
| Not available | *Jaculus orientalis* | 2.1367 | 0.01964846 | 3 |
| Not available | *Mustela nivalis* | 2.15 | 0.00409806 | 3 |
| Not available | *Psammomys obesus* | 2.2304 | 0.37093454 | 3 |
| Not available | *Spalax ehrenbergi* | 2.2455 | 0.00670044 | 3 |
| Not available | *Spalax leucodon* | 2.2504 | 4.7607E-05 | 3 |
| Not available | *Myoxis glis* | 2.2844 | 0.0637705 | 3 |
| Not available | *Nesokia indica* | 2.2911 | 0.00026476 | 3 |
| Not available | *Sciurus anomalus* | 2.4082 | **0.59841321** | 4 |
| Not available | *Rattus norvegicus* | 2.4548 | 0.11551963 | 4 |
| Not available | *Hemiechinus auritus* | 2.4713 | 0.00569106 | 4 |
| Not available | *Vormela peregusna* | 2.7924 | **0.97598374** | 5 |
| Not available | *Erinaceus concolor* | 2.8561 | 0.18601841 | 5 |
| Not available | *Martes foina* | 3 | **0.63584471** | 5 |
| Not available | *Genetta genetta* | 3.2355 | **0.88513038** | 6 |
| Not available | *Lepus capensis* | 3.3096 | 0.21200265 | 6 |
| Not available | *Felis silvestris* | 3.3847 | 0.21628106 | 6 |
| Not available | *Herspestes ichneumon* | 3.4742 | 0.29991244 | 6 |
| Not available | *Procavia capensis* | 3.5635 | 0.29799738 | 6 |
| Not available | *Vulpes vulpes* | 3.6776 | 0.43213778 | 6 |
| Not available | *Lutra lutra* | 3.7959 | 0.45873431 | 6 |
| Not available | *Felis chaus* | 3.8169 | 0.0072205 | 6 |
| Not available | *Mellivora capensis* | 3.8993 | 0.25255602 | 6 |
| Not available | *Meles meles* | 3.9638 | 0.14985204 | 6 |
| Not available | *Canis aureus* | 3.9722 | 0.00036922 | 6 |
| Not available | *Lynx caracal* | 3.9906 | 0.00474853 | 6 |
| Not available | *Capreolus capreolus* | 4.0792 | 0.28519175 | 6 |
| Not available | *Hystrix indica* | 4.143 | 0.14678435 | 6 |
| Not available | *Gazella gazella* | 4.2279 | 0.25800106 | 6 |
| Not available | *Lynx lynx* | 4.2298 | 4.51E-07 | 6 |
| Not available | *Gazella dorcas* | 4.3617 | **0.50763507** | 7 |
| Not available | *Panthera pardus* | 4.3979 | 0.031846 | 7 |
| Not available | *Ovis aries* | 4.5051 | 0.35712428 | 7 |
| Not available | *Hyaena hyaena* | 4.5152 | 0.00044693 | 7 |

| | | | | |
|---|---|---|---|---|
| Not available | *Canis lupus* | 4.632 | 0.38896612 | 7 |
| Not available | *Acinonyx jubatus* | 4.6853 | 0.06997048 | 7 |
| Not available | *Cervus dama* | 4.7304 | 0.04752478 | 7 |
| Not available | *Sus scrofa* | 4.7404 | 0.00033963 | 7 |
| Not available | *Capra ibex* | 4.8463 | 0.27856229 | 7 |
| Not available | *Capra hircus* | 4.8751 | 0.00934418 | 7 |
| Not available | *Alcephalus busephalus* | 5.1335 | **0.76617219** | 8 |
| Not available | *Panthera leo* | 5.1614 | 0.0044551 | 8 |
| Not available | *Cervus elaphus* | 5.1761 | 0.00055432 | 8 |
| Not available | *Ursus arctos* | 5.2467 | 0.06324967 | 8 |
| Not available | *Equus onager* | 5.3444 | 0.12296445 | 8 |

**Body mass estimate not available**

| | |
|---|---|
| Not available | *Myomimus roachi* |
| Not available | *Acomys cilicicus* |
| Not available | *Microtus irani* |
| Not available | *Pitymys majori* |

**SPAIN**

| | | | | |
|---|---|---|---|---|
| Not available | *Suncus etruscus* | 0.3522 | 0 | 1 |
| Not available | *Sorex minutus* | 0.4771 | 0.14880091 | 1 |
| Not available | *Micromys minutus* | 0.7559 | **0.74173743** | 1 |
| Not available | *Sorex granarius* | 0.7959 | 0.02410316 | 1 |
| Not available | *Crocidura russula* | 0.8062 | 0.00037327 | 1 |
| Not available | *Crocidura suaveolens* | 0.8254 | 0.00218222 | 1 |
| Not available | *Mus spretus* | 1.0899 | **0.86627616** | 2 |
| Not available | *Neomys fodiens* | 1.1139 | 0.00985712 | 2 |
| Not available | *Neomys anomalus* | 1.1335 | 0.00494538 | 2 |
| Not available | *Pitymys lusitanicus* | 1.2122 | 0.22130097 | 2 |
| Not available | *Microtus arvalis* | 1.2617 | 0.08641096 | 2 |
| Not available | *Mus domesticus* | 1.2833 | 0.0068934 | 2 |
| Not available | *Clethrionomys glareolus* | 1.2878 | 5.3192E-05 | 2 |
| Not available | *Apodemus sylvaticus* | 1.3444 | 0.11766254 | 2 |
| Not available | *Microtis agrestis* | 1.3444 | 0 | 2 |
| Not available | *Pitymys duodecimcostatus* | 1.345 | 4.83E-07 | 2 |
| Not available | *Talpa caeca* | 1.5051 | **0.67149229** | 3 |
| Not available | *Microtus nivalis* | 1.5911 | 0.27993905 | 3 |
| Not available | *Galemys pyrenaicus* | 1.7597 | **0.69121963** | 3 |
| Not available | *Talpa europaea* | 1.8808 | 0.45132386 | 3 |
| Not available | *Talpa romana* | 1.9661 | 0.23678438 | 3 |

| | | | | |
|---|---|---|---|---|
| Not available | *Eliomys quercinus* | 1.98 | 0.00168398 | 3 |
| Not available | *Rattus rattus* | 2.0917 | 0.36281463 | 3 |
| Not available | *Mustela nivalis* | 2.15 | 0.09572566 | 3 |
| Not available | *Arvicola sapidus* | 2.2304 | 0.18031045 | 3 |
| Not available | *Myoxis glis* | 2.2844 | 0.07418324 | 3 |
| Not available | *Sciurus vulgaris* | 2.3979 | 0.32112847 | 3 |
| Not available | *Rattus norvegicus* | 2.4548 | 0.0747487 | 3 |
| Not available | *Erinaceus europaeus* | 2.8048 | **0.92528736** | 4 |
| Not available | *Erinaceus algirus* | 2.8451 | 0.02484538 | 4 |
| Not available | *Mustela putorius* | 3 | 0.46874256 | 4 |
| Not available | *Martes foina* | 3 | 0 | 4 |
| Not available | *Oryctolagus cuniculus* | 3.1959 | **0.62632266** | 5 |
| Not available | *Genetta genetta* | 3.2355 | 0.02433209 | 5 |
| Not available | *Lepus capensis* | 3.3096 | 0.11760215 | 5 |
| Not available | *Lepus granatensis* | 3.3341 | 0.00499673 | 5 |
| Not available | *Felis silvestris* | 3.3847 | 0.04718528 | 5 |
| Not available | *Herspestes ichneumon* | 3.4742 | 0.17562781 | 5 |
| Not available | *Vulpes vulpes* | 3.6776 | **0.6234407** | 6 |
| Not available | *Lutra lutra* | 3.7959 | 0.27089926 | 6 |
| Not available | *Meles meles* | 3.9638 | 0.43993997 | 6 |
| Not available | *Lynx pardinus* | 4.0434 | 0.09485615 | 6 |
| Not available | *Macaca sylvanus* | 4.0492 | 2.4368E-05 | 6 |
| Not available | *Capreolus capreolus* | 4.0792 | 0.00478043 | 6 |
| Not available | *Castor fiber* | 4.1446 | 0.05190463 | 6 |
| Not available | *Canis lupus* | 4.632 | **0.90340332** | 7 |
| Not available | *Sus scrofa* | 4.7404 | 0.07436462 | 7 |
| Not available | *Capra pyrenaica* | 4.7597 | 0.00022835 | 7 |
| Not available | *Cervus elaphus* | 5.1761 | **0.57890266** | 7 |
| Not available | *Ursus arctos* | 5.2467 | 0.0047192 | 7 |

**Body mass estimate not available**

| | | | | |
|---|---|---|---|---|
| Not available | *Microtus cabrerae* | | | |

**GREECE**

| | | | | |
|---|---|---|---|---|
| Not available | *Suncus estruscus* | 0.3617 | 0 | 1 |
| Not available | *Sorex minutus* | 0.4771 | 0.1341456 | 1 |
| Not available | *Micromys minutus* | 0.7559 | 0.7610376 | 1 |
| Not available | *Crocidura suaveolens* | 0.8261 | 0.1196144 | 1 |
| Not available | *Sorex araneus* | 0.8513 | 0.0077931 | 1 |
| Not available | *Crocidura leucodon* | 0.8921 | 0.0367048 | 1 |

| | | | | |
|---|---|---|---|---|
| Not available | *Neomys fodiens* | 1.1139 | **0.828914** | 2 |
| Not available | *Apodemus microps* | 1.233 | **0.5107209** | 2 |
| Not available | *Pitymys subterraneus* | 1.233 | 0 | 2 |
| Not available | *Clethrionomys glareolus* | 1.281 | 0.102587 | 2 |
| Not available | *Mus abbotti* | 1.2833 | 6.48E-07 | 2 |
| Not available | *Apodemus agrarius* | 1.3075 | 0.0183305 | 2 |
| Not available | *Muscardinus avellanarius* | 1.3444 | 0.0523151 | 2 |
| Not available | *Apodemus flavicollis* | 1.3541 | 0.0008296 | 2 |
| Not available | *Apodemus sylvaticus* | 1.3962 | 0.080447 | 2 |
| Not available | *Neomys anomalus* | 1.3979 | 7.16E-07 | 2 |
| Not available | *Dryomys nitedula* | 1.4082 | 0.0012833 | 2 |
| Not available | *Talpa caeca* | 1.5051 | **0.4257985** | 3 |
| Not available | *Microtus nivalis* | 1.5911 | 0.3578062 | 3 |
| Not available | *Mesocricetus migratorius* | 1.5977 | 0.0003411 | 3 |
| Not available | *Apodemmus mystacinus* | 1.659 | 0.1957847 | 3 |
| Not available | *Dinaromys bogdanovi* | 1.7482 | 0.3682682 | 3 |
| Not available | *Talpa europaea* | 1.8808 | **0.6190639** | 4 |
| Not available | *Eliomys quercinus* | 1.98 | 0.4039325 | 4 |
| Not available | *Rattus rattus* | 2.0917 | **0.4566521** | 4 |
| Not available | *Arvicola terrestris* | 2.1139 | 0.0083385 | 4 |
| Not available | *Mustela nivalis* | 2.1501 | 0.0373806 | 4 |
| Not available | *Spalax leucodon* | 2.2504 | 0.3382279 | 4 |
| Not available | *Glis glis* | 2.2844 | 0.0246407 | 4 |
| Not available | *Mesocricetus newtoni* | 2.2956 | 0.000845 | 4 |
| Not available | *Spermophilus citellus* | 2.3829 | 0.2255985 | 4 |
| Not available | *Rattus norvegicus* | 2.4548 | 0.1337042 | 4 |
| Not available | *Sciurus vulgaris* | 2.5599 | 0.2598376 | 4 |
| Not available | *Erinaceus concolor* | 2.8561 | **0.8024956** | 5 |
| Not available | *Martes foina* | 3 | 0.262113 | 5 |
| Not available | *Lepus capensis* | 3.334 | **0.6922408** | 5 |
| Not available | *Felis silvestris* | 3.5623 | 0.3730416 | 5 |
| Not available | *Vulpes vulpes* | 3.6776 | 0.0890582 | 5 |
| Not available | *Lutra lutra* | 3.9125 | 0.3600744 | 5 |
| Not available | *Meles meles* | 3.937 | 0.0007909 | 5 |
| Not available | *Lynx lynx* | 4.2298 | **0.4954624** | 6 |
| Not available | *Capreolus capreolus* | 4.3883 | 0.1717944 | 6 |
| Not available | *Canis lupus* | 4.632 | 0.3693148 | 6 |
| Not available | *Cervus dama* | 4.6857 | 0.0079038 | 6 |
| Not available | *Ursus arctos* | 5.0253 | **0.525373** | 7 |
| Not available | *Sus scrofa* | 5.1761 | 0.0901515 | 7 |
| Not available | *Cervus elaphus* | 5.1875 | 2.334E-05 | 7 |
| Not available | *Panthera leo* | 5.1931 | 1.001E-06 | 7 |

**Body mass estimate not available**

| | | |
|---|---|---|
| Not available | *Myomimus roachi* | |
| Not available | *Microtus epiroticus* | |
| Not available | *Pitymys thomasi* | |

**NON-INDIGENOUS SPECIES**

| | | |
|---|---|---|
| domestic goat | *Capra hircus* | 4.8751 |
| **Post-glacial invasions, omitted from lump analysis:** | | |
| Not available | *Canis aureus* | 3.8129 |
| Not available | *Vormela peregusna* | 2.7924 |
| Not available | *Microtus guentheri* | 1.711 |
| Not available | *Mus domesticus* | 1.2833 |

**SOUTH AFRICA**

| | | | | |
|---|---|---|---|---|
| Pygmy mouse | *Mus minutoides* | 0.7672 | 0 | 1 |
| Lesser dwarf shrew | *Suncus varilla* | 0.8129 | 0.021548 | 1 |
| Grey climbing mouse | *Dendromus melanotis* | 0.8261 | 0.00039 | 1 |
| Reddish-grey musk shrew | *Crocidura cyanea* | 0.9345 | 0.2299247 | 1 |
| Brant's climbing mouse | *Dendromus mesomelas* | 1.0531 | 0.3183427 | 1 |
| Large-eared mouse | *Malacothrix typica* | 1.1271 | 0.1427079 | 1 |
| Forest shrew | *Myosorex varius* | 1.1303 | 3.55E-06 | 1 |
| Cape spiny mouse | *Acomys subspinosus* | 1.3253 | **0.7251363** | 2 |
| Kreb's fat mouse | *Steatomys krebsi* | 1.3802 | 0.1032533 | 2 |
| Woodland dormouse | *Graphiurus murinus* | 1.4502 | 0.1807721 | 2 |
| Hairy-footed gerbil | *Gerbillurus paeba* | 1.5105 | 0.1411587 | 2 |
| Striped mouse | *Rhabdomys pumilo* | 1.5593 | 0.0838416 | 2 |
| Round-eared elephant shrew | *Macroscelides proboscideus* | 1.5821 | 0.0110977 | 2 |
| Verreaux's mouse | *Myomyscus verroxii* | 1.6128 | 0.0271424 | 2 |
| Short-tailed gerbil | *Desmmodillus auricularis* | 1.6637 | 0.1013455 | 2 |
| Namaqua rock mouse | *Aethomys namequensis* | 1.6884 | 0.0141219 | 2 |
| Cape golden mole | *Chrysochloris asiatica* | 1.6902 | 6.97E-07 | 2 |
| Hottentot golden mole | *Amblysomus hottentotus* | 1.8319 | **0.6316147** | 3 |
| Spectacled dormouse | *Graphiurus ocularis* | 1.8376 | 8.43E-05 | 3 |
| Common molerat | *Cryptomys hottentotus* | 1.8965 | 0.1579827 | 3 |
| White-tailed mouse | *Mystromys albicaudatus* | 1.9388 | 0.0731168 | 3 |
| Water rat | *Dasymys incomtus* | 1.9724 | 0.038797 | 3 |
| Cape gerbil | *Tatera afra* | 1.9868 | 0.0026593 | 3 |
| Saunder's vlei rat | *Otomys saundersiae* | 2.0128 | 0.0180571 | 3 |
| Vlei rat | *Otomys irroratus* | 2.0719 | 0.1596412 | 3 |

| | | | | |
|---|---|---|---|---|
| Greater musk shrew | *Crocidura flavescens* | 2.0878 | 0.0035402 | 3 |
| Bush karoo rat | *Otomys unisulcatus* | 2.0952 | 0.0003434 | 3 |
| Laminate vlei rat | *Otomys laminatus* | 2.1761 | 0.2845926 | 3 |
| Cape molerat | *Georychus capensis* | 2.3385 | **0.7224258** | 4 |
| Striped Weasel | *Poecilogale albinucha* | 2.3385 | 0 | 4 |
| Cape dune molerat | *Bathyergus suillus* | 2.7959 | **0.9910413** | 4 |
| Striped polecat | *Ictonyx striatus* | 2.8663 | 0.1980116 | 4 |
| Small grey mongoose | *Herpestes pulverulenta* | 2.9015 | 0.0366278 | 4 |
| Yellow mongoose | *Cynictis penicillata* | 2.9189 | 0.0048343 | 4 |
| Smith's red rock rabbit | *Pronolagus rupestris* | 3.2095 | **0.943092** | 5 |
| Large-spotted genet | *Genetta tigrina* | 3.2695 | 0.1388286 | 5 |
| Small-spotted genet | *Genetta genetta* | 3.2788 | 0.0004677 | 5 |
| Cape hare | *Lepus capensis* | 3.3096 | 0.0256865 | 5 |
| Cape fox | *Vulpes chama* | 3.4232 | 0.451537 | 5 |
| Rock dassie | *Procavia capensis* | 3.4804 | 0.1255921 | 5 |
| Water mongoose | *Atilax paludinosus* | 3.5315 | 0.1004335 | 5 |
| Scrub hare | *Lepus saxatilis* | 3.5557 | 0.0106145 | 5 |
| African wildcat | *Felis libyca* | 3.6335 | 0.2452151 | 5 |
| Aardwolf | *Proteles cristatus* | 3.8404 | **0.8182416** | 6 |
| Black-backed jackal | *Canis mesomelas* | 3.8982 | 0.1182397 | 6 |
| Honey badger | *Mellivora capensis* | 3.8993 | 5.51E-07 | 6 |
| Klipspringer | *Oreotragus oreotragus* | 4.0086 | 0.4045709 | 6 |
| Grysbok | *Raphicerus melanotis* | 4.0107 | 5.16E-07 | 6 |
| Caracal | *Felis caracal* | 4.0294 | 0.0050279 | 6 |
| Serval | *Felis serval* | 4.0473 | 0.0039593 | 6 |
| Steenbok | *Raphicerus campestris* | 4.0531 | 5.673E-05 | 6 |
| clawless otter | *Aonyx capensis* | 4.0607 | 0.0002252 | 6 |
| porcupine | *Hystrix africaeaustralis* | 4.0969 | 0.0331825 | 6 |
| Grey duiker | *Sylvicapra grimmia* | 4.2068 | 0.3776734 | 6 |
| Grey ribbok | *Pelea capreolus* | 4.3522 | **0.5278384** | 7 |
| Chacma baboon | *Papio ursinus* | 4.3655 | 0.0012823 | 7 |
| Leopard | *Panthera pardus* | 4.4158 | 0.0622937 | 7 |
| Brown hyaena | *Hyaena brunnea* | 4.5826 | **0.5617227** | 8 |
| Aardvark | *Orycteropus afer* | 4.7189 | 0.3791114 | 8 |
| Bontebuck | *Damaliscus dorcas dorcas* | 4.8261 | 0.2211783 | 8 |
| Hartebeest | *Alcelaphus buselaphus* | 5.1335 | **0.7661702** | 9 |
| Lion | *Panthera leo* | 5.1931 | 0.0255779 | 9 |
| Cape mountain zebra | *Equus zebra* | 5.3883 | 0.3197281 | 9 |
| Eland | *Taurotragus oryx* | 5.5866 | 0.234796 | 9 |
| Black rhinoceros | *Diceros bicornis* | 5.9385 | 0.3874952 | 9 |

**No body mass estimate available**

| | | | | |
|---|---|---|---|---|
| bluebuck | *Hippotragus leucophaeus* | | | |

**NON-INDIGENOUS SPECIES**

| | | | | |
|---|---|---|---|---|
| house mouse | *Mus musculus* | 1.2055 | | |
| Black rat | *Rattus rattus* | 2.0445 | | |
| Norway rat | *Rattus norvegicus* | 2.4548 | | |
| grey squirrel | *Sciurus carolinensis* | 2.7634 | | |
| Domestic cat | *Felis catus* | 3.5334 | | |
| Himalayan tahr | *Hemitragus jemlahicus* | 4.1673 | | |
| Fallow deer | *Cervus dama* | 4.6857 | | |
| Feral Pig | *Sus scrofa* | 4.7404 | | |

**SOUTHWESTERN AUSTRALIA**

| | | | | |
|---|---|---|---|---|
| Honey possum | *Tarsipes rostratus* | 0.9542 | 0 | 1 |
| Western pygmy-possum | *Cercartetus concinnus* | 1.1139 | **0.41668946** | 1 |
| Little long-tailed dunnart | *Sminthopsis dolichura* | 1.1335 | 0.00220565 | 1 |
| Fat-tailed dunnart | *Sminthopsis crassicaudata* | 1.1761 | 0.02817809 | 1 |
| Grey-bellied dunnart | *Sminthopsis griseoventer* | 1.243 | 0.10626001 | 1 |
| Gilbert's dunnart | *Sminthopsis gilberti* | 1.29 | 0.04929077 | 1 |
| White-tailed dunnart | *Sminthopsis granulipes* | 1.3979 | 0.3296994 | 1 |
| Ash-grey mouse | *Pseudomys albocinereus* | 1.4843 | 0.24228632 | 1 |
| Western chestnut mouse | *Pseudomys nanus* | 1.5315 | 0.06393275 | 1 |
| Western mouse | *Pseudomys occidentalis* | 1.5315 | 0 | 1 |
| Spinifex hopping mouse | *Notomys alexis* | 1.5441 | 0.0011658 | 1 |
| Yellow-footed antechinus | *Antichinus flavipes* | 1.6532 | 0.39108584 | 1 |
| Shark Bay mouse | *Pseudomys fieldi* | 1.6532 | 0 | 1 |
| Red-tailed phascogale | *Phascogale calura* | 1.7118 | 0.12057156 | 1 |
| Mitchell's hopping mouse | *Notomys mitchelli* | 1.716 | 0.00003029 | 1 |
| Southern Dibbler | *Parantechinus apicalis* | 1.8373 | **0.46422164** | 2 |
| Heath rat | *Pseudomys shortridgei* | 1.8451 | 0.00022366 | 2 |
| Long-tailed hopping mouse | *Notomys longicaudatus* | 2 | **0.62084543** | 2 |
| Pale field-rat | *Rattus tunneyi* | 2.0934 | 0.29249337 | 2 |
| Bush rat | *Rattus fuscipes* | 2.1222 | 0.01591033 | 2 |
| Brush-tailed phascogale | *Phascogale tapoatafa* | 2.2867 | **0.62654554** | 3 |
| Western barred bandicoot | *Perameles bougainville* | 2.3541 | 0.14038673 | 3 |
| Numbat | *Myrmecobius fasciatus* | 2.6735 | **0.92970393** | 3 |
| Water rat | *Hydromys chrysogaster* | 2.8328 | **0.56656272** | 4 |
| Southern brown bandicoot | *Isoodon obesulus* | 2.8893 | 0.08191166 | 4 |

| | | | | |
|---|---|---|---|---|
| Western ringtail possum | *Pseudocheirus occidentalis* | 3 | 0.33785204 | 4 |
| Western quoll | *Dasyurus geoffroii* | 3.0414 | 0.03685756 | 4 |
| long-nosed potoroo | *Potorus tridactylus* | 3.0414 | 0 | 4 |
| Rufous hare-wallaby | *Lagorchestes hirsutus* | 3.1021 | 0.09668033 | 4 |
| Brush-tailed bettong | *Bettongia penicillata* | 3.1139 | 0.00065632 | 4 |
| Burrowing betong | *Bettongia leseur* | 3.1761 | 0.10521652 | 4 |
| Banded hare-wallaby | *Lagostrophus fasciatus* | 3.2304 | 0.07245019 | 4 |
| Common brushtail possum | *Trichosurus vulpecula* | 3.4191 | **0.64934269** | 5 |
| Quokka | *Setonix brachyurus* | 3.5119 | 0.2126823 | 5 |
| Crescent nailtail wallaby | *Onychogalea lunata* | 3.5441 | 0.01270999 | 5 |
| Black-footed rock-wallaby | *Petrogale lateralis* | 3.6021 | 0.06415376 | 5 |
| Short-beaked echidna | *Tachyglossus aculeatus* | 3.6532 | 0.04465201 | 5 |
| Tammar wallaby | *Macropus eugenii* | 3.8129 | 0.4258 | 5 |
| Western brush wallaby | *Macropus irma* | 3.9031 | 0.12385832 | 5 |
| Dingo | *Canis lupus* | 4.2253 | **0.71230509** | 6 |
| Common wallaroo | *Macropus robustus* | 4.3275 | 0.06202985 | 6 |
| Western grey kangaroo | *Macropus fuliginosus* | 4.3449 | 0.00015354 | 6 |

**No body mass estimate available**

| | |
|---|---|
| Big-eared hopping mouse | *Notomys macrotis* |
| Broad-faced potoroo | *Potorous platyops* |

**NON-INDIGENOUS SPECIES**

| | | |
|---|---|---|
| House mouse | *Mus musculus* | 1.2175 |
| Black rat | *Rattus rattus* | 2.4472 |
| Brown rat | *Rattus norvegicus* | 2.5051 |
| European rabbit | *Oryctolagus cuniculus* | 3.1987 |
| Cat | *Felis catus* | 3.6258 |
| Red fox | *Vulpes vulpes* | 3.7745 |
| Goat | *Capra hircus* | 4.525 |
| Feral hog | *Sus scrofa* | 4.9358 |

**SOUTHCENTRAL AUSTRALIA**

| | | | | |
|---|---|---|---|---|
| Narrow-nosed planigale | *Planigale tenuirostris* | 0.7818 | 0 | 1 |
| Feathertail glider | *Acrobates pygmaeus* | 1.0792 | 0.36436009 | 1 |
| Western pygmy-possum | *Cercartetus concinnus* | 1.1139 | 0.00174145 | 1 |
| Fat-tailed dunnart | *Sminthopsis crassicaudata* | 1.1761 | 0.01223591 | 1 |
| Stripe-faced dunnart | *Sminthopsis macroura* | 1.301 | 0.0927543 | 1 |
| Mitchell's hopping mouse | *Notomys mitchelli* | 1.716 | **0.71440325** | 2 |
| Plains rat | *Pseudomys australis* | 1.8129 | 0.05471827 | 2 |

| | | | | |
|---|---|---|---|---|
| Bush rat | *Rattus fuscipes* | 2.1222 | **0.58848407** | 2 |
| Brush-tailed phascogale | *Phascogale tapoatafa* | 2.2867 | 0.28174709 | 2 |
| Pig-footed bandicoot | *Chaeropus ecaudatus* | 2.301 | 0.00023056 | 2 |
| Western barred bandicoot | *Perameles bougainville* | 2.3541 | 0.02202046 | 2 |
| Numbat | *Myrmecobius fasciatus* | 2.6735 | **0.797635** | 3 |
| Water rat | *Hydromys chrysogaster* | 2.8328 | **0.42893843** | 3 |
| Southern brown bandicoot | *Isoodon obesulus* | 2.8893 | 0.05341621 | 3 |
| Common ringtail possum | *Pseudocheirus peregrinus* | 2.9542 | 0.08028668 | 3 |
| Eastern Quoll | *Dasyurus viverrinus* | 3.0374 | 0.14705267 | 3 |
| Western quoll | *Dasyurus geoffroii* | 3.0414 | 9.032E-06 | 3 |
| Brush-tailed bettong | *Bettongia penicillata* | 3.1139 | 0.1082364 | 3 |
| Burrowing betong | *Bettongia leseur* | 3.1761 | 0.07247905 | 3 |
| Common brushtail possum | *Trichosurus vulpecula* | 3.4191 | **0.72084238** | 4 |
| Crescent nailtail wallaby | *Onychogalea lunata* | 3.5441 | 0.28039793 | 4 |
| Short-beaked echidna | *Tachyglossus aculeatus* | 3.6532 | 0.2053762 | 4 |
| Tammar wallaby | *Macropus eugenii* | 3.8129 | 0.39583245 | 4 |
| Yellow-footed rock-wallaby | *Petrogale xanthopus* | 3.9294 | 0.22662335 | 4 |
| Koala | *Phascolarctos cinereus* | 4.0107 | 0.10235448 | 4 |
| Dingo | *Canis lupus* | 4.2253 | **0.57132462** | 5 |
| Common wallaroo | *Macropus robustus* | 4.3275 | 0.15314142 | 5 |
| Western grey kangaroo | *Macropus fuliginosus* | 4.3449 | 0.00070421 | 5 |
| S. hairy-nosed wombat | *Lasiorhinus latifrons* | 4.4065 | 0.03556888 | 5 |
| Common wombat | *Vombatus ursinus* | 4.415 | 5.4723E-05 | 5 |
| Red kangaroo | *Macropus rufus* | 4.6651 | **0.48155015** | 5 |

**NON-INDIGENOUS SPECIES**

| | | |
|---|---|---|
| Brown rat | *Rattus norvegicus* | 2.5051 |
| Black rat | *Rattus rattus* | 2.4472 |
| Red fox | *Vulpes vulpes* | 3.7745 |
| Cat | *Felis catus* | 3.6258 |
| European rabbit | *Oryctolagus cuniculus* | 3.1987 |
| Brown hare | *Lepus capensis* | 3.6021 |
| Feral hog | *Sus scrofa* | 4.9358 |
| Goat | *Capra hircus* | 4.525 |
| Fallow deer | *Dama dama* | 4.6857 |
| House mouse | *Mus musculus* | 1.2175 |

[1] Data is arranged by ecosystem, and includes species common name, latin name, log body mass, gap statistic, and lump membership. All body masses are from Silva and Downing (1995), except for Australian data sets which are from Strahan (1995), and Chile data, which are primarily from Redford and Eisenberg (1989).

APPENDIX G
ABUNDANCE, DECLINE AND NOMADISM IN THE FAUNA
OF MEDITERRANEAN-CLIMATE ECOSYSTEMS

**ITALY BIRDS**[1]

| Species | Abun. | Mass | RGS | Lump | Trend | Status |
|---|---|---|---|---|---|---|
| *Regulus ignicapillus* | 0.001 | 0.74819 | 0 | 1 | Secure | Secure |
| *Cisticola juncidis* | 0.001 | 0.84819 | **0.75687** | 1 | Secure | Secure |
| *Phylloscopus bonelli* | 0.009 | 0.85733 | 0.00683 | 1 | Secure | Secure |
| *Phylloscopus collybitta* | 0.038 | 0.87506 | 0.05099 | 1 | Secure | Secure |
| *Aegithalos caudatus* | 0.005 | 0.91381 | 0.33275 | 1 | Secure | Secure |
| *Certhia brachydactyla* | 0.001 | 0.92942 | 0.05745 | 1 | Secure | Secure |
| *Parus ater* | 0.002 | 0.95904 | 0.26023 | 1 | Secure | Secure |
| *Troglodytes troglodytes* | 0.034 | 0.96848 | 0.0162 | 1 | Secure | Secure |
| *Parus palustris* | 0.002 | 1.02531 | **0.72684** | 2 | Secure | Secure |
| *Sylvia cantillans* | 0.016 | 1.03342 | 0.01575 | 2 | Secure | Secure |
| *Hippolais polyglotta* | 0.01 | 1.04139 | 0.0132 | 2 | Secure | Secure |
| *Serinus serinus* | 0.024 | 1.04922 | 0.01365 | 2 | Secure | Secure |
| *Sylvia melanocephala* | 0.011 | 1.05308 | 0.00146 | 2 | Secure | Secure |
| *Parus caeruleus* | 0.022 | 1.12385 | **0.8937** | 3 | Secure | Secure |
| *Cettia cettii* | 0.005 | 1.15381 | 0.42261 | 3 | Secure | Secure |
| *Sylvia communis* | 0.001 | 1.16137 | 0.01887 | 3 | Secure | Secure |
| *Muscicapa striata* | 0.003 | 1.16435 | 0.00066 | 3 | 0 | declining |
| *Phoenicurus phoenicurus* | 0 | 1.16435 | 0 | 3 | -1 | vulnerable |
| *Saxicola torquata* | 0.008 | 1.18469 | 0.22154 | 3 | 1+ | declining |
| *Sylvia atricapilla* | 0.138 | 1.19033 | 0.00926 | 3 | Secure | Secure |
| *Carduelis carduelis* | 0.023 | 1.19312 | 0.00068 | 3 | Secure | Secure |
| *Hirundo rustica* | 0.027 | 1.20412 | 0.05448 | 3 | -1 | declining |
| *Motacilla cinerea* | 0.001 | 1.24551 | **0.64543** | 4 | Secure | Secure |
| *Erithacus rubecula* | 0.069 | 1.26007 | 0.11508 | 4 | Secure | Secure |
| *Luscinia megarhyncos* | 0.011 | 1.26245 | 0.00032 | 4 | Secure | Secure |
| *Parus major* | 0.048 | 1.27875 | 0.14432 | 4 | Secure | Secure |
| *Dendrocopus minor* | 0.001 | 1.29667 | 0.17434 | 4 | Secure | Secure |
| *Fringilla coelebs* | 0.054 | 1.33041 | 0.48867 | 4 | Secure | Secure |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Pyrrhula pyrrhula* | 0.004 | 1.33846 | 0.02145 | 4 | Secure | Secure |
| *Passer montanus* | 0.002 | 1.34242 | 0.00183 | 4 | Secure | Secure |
| *Sitta europaea* | 0.012 | 1.34242 | 0 | 4 | Secure | Secure |
| *Motacilla alba* | 0.004 | 1.35603 | 0.08432 | 4 | Secure | Secure |
| *Emberiza cirlus* | 0.021 | 1.36361 | 0.01628 | 4 | Secure | Secure |
| *Anthus trivialis* | 0.001 | 1.36922 | 0.0055 | 4 | Secure | Secure |
| *Lullula arborea* | 0.001 | 1.42975 | **0.80925** | 5 | 0 | vulnerable |
| *Passer domesticus* | 0.049 | 1.44248 | 0.05259 | 5 | Secure | Secure |
| *Carduelis chloris* | 0.034 | 1.44404 | 6.9E-05 | 5 | Secure | Secure |
| *Lanius collurio* | 0.008 | 1.47567 | 0.35706 | 5 | -1 | declining |
| *Jinx torquilla* | 0.006 | 1.52504 | **0.59686** | 6 | -1 | declining |
| *Apus apus* | 0.009 | 1.57519 | 0.54541 | 6 | Secure | Secure |
| *Alauda arvensis* | 0.001 | 1.60152 | 0.16521 | 6 | -1 | vulnerable |
| *Emberiza calandra* | 0.002 | 1.66276 | **0.58137** | 7 | Secure | Secure |
| *Upupa epops* | 0.003 | 1.78817 | **0.88761** | 7 | Secure | Secure |
| *Turdus philomelos* | 0.004 | 1.83091 | 0.20535 | 7 | Secure | Secure |
| *Oriolus oriolus* | 0.008 | 1.89763 | 0.39542 | 7 | Secure | Secure |
| *Dendrocopus major* | 0.004 | 1.91169 | 0.00817 | 7 | Secure | Secure |
| *Sturnus vulgaris* | 0.01 | 1.9154 | 9.7E-05 | 7 | Secure | Secure |
| *Cuculus canorus* | 0.017 | 2.05308 | **0.78376** | 8 | Secure | Secure |
| *Turdus merula* | 0.145 | 2.05308 | 0 | 8 | Secure | Secure |
| *Streptopelia turtur* | 0.035 | 2.12057 | 0.27812 | 8 | 0 | declining |
| *Streptopelia decaocto* | 0.001 | 2.17319 | 0.14558 | 8 | Secure | Secure |
| *Garrulus glandarius* | 0.008 | 2.20683 | 0.03976 | 8 | Secure | Secure |
| *Picus viridus* | 0.005 | 2.24551 | 0.05067 | 8 | 0 | declining |
| *Corvus monedula* | 0.001 | 2.39094 | 0.49384 | 8 | Secure | Secure |
| *Corvus corone cornix* | 0.023 | 2.75587 | **0.69571** | 8 | Secure | Secure |
| *Buteo buteo* | 0.002 | 2.94201 | 0.08957 | 8 | Secure | Secure |

**SAN DIEGO BIRDS**

| Species | Summer abundance |
|---|---|
| *Archilochus costae* | fairly common |
| *Cynanthus latirostris* | - |
| *Archilochus alexandri* | fairly common |
| *Archilochus anna* | common |
| *Polioptila melanura* | uncommon and local |
| *Psaltriparius minimus* | very common |
| *Polioptila caerulea* | rare and local |
| *Wilsonia pusilla* | casual or former |
| *Dendroica nigrescens* | rare |

| | |
|---|---|
| *Vireo bellii pusillus* | uncommon and v. localized |
| *Vermivora celata* | uncommon to fairly common |
| *Carduelis psaltria* | common |
| *Dendroica petechia* | uncommon and local |
| *Thryomanes bewickii* | common |
| *Empidonax difficilis* | uncommon |
| *Geothlypis trichas* | fairly common to common |
| *Parus gambeli baileyae* | very common |
| *Troglodytes aedon* | common |
| *Carduelis lawrencei* | uncommon |
| *Cistothorus palustris* | fairly common but local |
| *Vireo huttoni huttoni* | uncomon |
| *Spizella atrogularis* | common |
| *Spizella passerina* | fairly common but local |
| *Salpinctes mexicanus* | uncommon |
| *Contopus sordidulus* | fairly common |
| *Vireo vicinior* | uncommon and v. localized |
| *Carduelis tristis* | common |
| *Empidonax traillii* | very rare |
| *Tachycineta thalassina* | common to v. common |
| *Chamaea fasciata* | common |
| *Vireo gilvus* | rare |
| *Stelgidopteryx ruficollis* | fairly common to common |
| *Passerina amoena* | fairly common |
| *Vireo solitarius* | rare |
| *Ammodramus savannarum* | uncommon and local |
| *Parus inornatus* | common |
| *Sayornis nigricans semiatra* | fairly common |
| *Aimophila ruficeps lambi* | uncommon to fairly common but local |
| *Aimophila belli* | uncommon to fairly common but local |
| *Zonotrichia melodia* | very common |
| *Sitta carolinensis aculeata* | fairly common |
| *Sayornis saya* | rare |
| *Carpodacus mexicanus* | v. common to abundant |
| *Hirundo pyrrhonota tachina* | abundant |
| *Phainopepla nitens lepida* | fairly common |
| *Icterus cucullatus nelsoni* | fairly common |
| *Carpodacus purpureus* | uncommon and local |
| *Icteria virens auricollis* | uncommon and local |
| *Dendrocopos pubescens* | rare to uncommon |
| *Myiarchus cinerascens* | uncommon to fairly common |
| *Sialia mexicana* | common to v. common |

| | |
|---|---|
| *Passerina caerulea* | uncommon |
| *Chondestes grammacus* | fairly common |
| *Pipilo chlorurus* | uncommon and local |
| *Catharus ustulatus* | rare and local |
| *Eremophila alpestris* | common |
| *Aeronautes saxatalis* | common to v. common |
| *Zonotrichia iliaca* | uncommon |
| *Icterus galbula parvus* | fairly common |
| *Dendrocopos nuttallii* | fairly common |
| *Campylorhynchus brunneicapillus* | uncommon and local |
| *Tyrannus verticalis* | fairly common |
| *Pipilo erythrophthalmus* | common |
| *Pheucticus melanocephalus* | fairly common |
| *Molothrus ater* | common |
| *Pipilo fuscus senicula* | common to v. common |
| *Tyrannus vociferans vociferans* | uncommon |
| *Lanius ludovicianus* | fairly common |
| *Mimus polyglottos polyglottos* | common |
| *Progne subis subis* | rare and local |
| *Chordeiles acutipennis texensis* | uncommon to fairly common |
| *Phalaenoptilus nuttallii* | uncommon |
| *Agelaius phoeniceus* | common to abundant |
| *Agelaius tricolor* | very common to abundant but local |
| *Euphagus cyanocephalus* | common |
| *Coccyzus americanus* | extirpated |
| *Xanthocephalus xanthocephalus* | very rare |
| *Porzana carolina* | very rare |
| *Aphelocoma coerulescens* | common |
| *Melanerpes formicivorus* | common |
| *Rallus limicola limicola* | uncommon |
| *Toxostoma redivivum* | fairly common to common |
| *Ixobrychus exilis hesperis* | rare |
| *Charadrius vociferus* | very common |
| *Sturnella neglecta* | common |
| *Falco sparverius* | fairly common |
| *Zenaida macroura marginella* | v. common to abundant |
| *Colaptes auratus* | uncommon |
| *Cyanocitta stelleri frontalis* | fairly common to common |
| *Otus kennicottii cardonensis* | uncommon to common |
| *Athene cunicularia hypugaea* | uncommon |
| *Callipepla gambelii gambelii* | fairly common to common |
| *Callipepla californica* | common to v. common |

| | |
|---|---|
| *Ardeola striata anthonyi* | uncommon to fairly common |
| *Callipepla picta eremophila* | fairly common |
| *Asio otus wilsonianus* | extirpiated |
| *Elanus leucurus majusculus* | fairly common |
| *Egretta ibis ibis* | fairly common to common |
| *Geoccyx californianus* | uncommon |
| *Columba fasciata monilis* | fairly common to common |
| *Circus cyaneus hudsonius* | rare, local |
| *Accipiter cooperii* | rare |
| *Corvus brachyrhynchos* | common to v. common |
| *Tyto alba pratincola* | uncommon |
| *Buteo lineatus* | uncommon to fairly common |
| *Strix occidentalis occidentalis* | rare and local |
| *Falco mexicanus* | rare |
| *Dendrocygna bicolor* | extirpiated |
| *Falco peregrinus* | extiriated, formerly rare |
| *Nycticorax nycticorax hoactli* | uncommon to fairly common |
| *Buteo swainsoni* | extirpiated |
| *Buteo jamaicensis* | fairly common |
| *Corvus corax clarionensis* | fairly common to common |
| *Bubo virginianus* | uncommon |
| *Cathartes aura* | rare to uncommon |
| *Aquila chrysaetos canadensis* | uncommon |
| *Gymnogyps californicus* | extirpiated |

## SOUTHCENTAL AUSTRALIAN MAMMALS

| Species | Status |
|---|---|
| *Planigale tenuirostris* | sparse |
| *Acrobates pygmaeus* | common |
| *Cercartetus concinnus* | common |
| *Sminthopsis crassicaudata* | common |
| *Sminthopsis macroura* | ? |
| *Notomys mitchelli* | common |
| *Pseudomys australis* | locally extinct |
| *Rattus fuscipes* | locally extinct |
| *Phascogale tapoatafa* | locally extinct |
| *Chaeropus ecaudatus* | extinct |
| *Perameles bougainville* | locally extinct |
| *Myrmecobius fasciatus* | locally extinct |
| *Hydromys chrysogaster* | sparse to common |

| | |
|---|---|
| *Isoodon obesulus* | >50% decline |
| *Pseudocheirus peregrinus* | common |
| *Dasyurus viverrinus* | locally extinct |
| *Dasyurus geoffroii* | locally extinct |
| *Bettongia penicillata* | locally extinct |
| *Bettongia leseur* | locally extinct |
| *Trichosurus vulpecula* | declining (#'s) |
| *Onychogalea lunata* | extinct |
| *Tachyglossus aculeatus* | common |
| *Macropus eugenii* | locally extinct |
| *Petrogale xanthopus* | decline (#s) |
| *Phascolarctos cinereus* | common |
| *Canis lupus* | locally extinct |
| *Macropus robustus* | abundant |
| *Macropus fuliginosus* | abundant |
| *Lasiorhinus latifrons* | common |
| *Vombatus ursinus* | locally extinct |
| *Macropus rufus* | abundant |

## SOUTHWESTERN AUSTRALIAN MAMMALS

| Species | Status |
|---|---|
| *Tarsipes rostratus* | common |
| *Cercartetus concinnus* | common |
| *Sminthopsis dolichura* | common |
| *Sminthopsis crassicaudata* | common |
| *Sminthopsis griseoventer* | common |
| *Sminthopsis gilberti* | common |
| *Sminthopsis granulipes* | common |
| *Pseudomys albocinereus* | OK ("sparse"), some range decline |
| *Pseudomys nanus* | locally extinct |
| *Pseudomys occidentalis* | commmon |
| *Notomys alexis* | common |
| *Antichinus flavipes* | abundant |
| *Pseudomys fieldi* | locally extinct |
| *Phascogale calura* | common but decline |
| *Notomys mitchelli* | common/some range decline |
| *Parantechinus apicalis* | rare/decline |
| *Pseudomys shortridgei* | rare-decline |
| *Notomys longicaudatus* | locally extinct/extinct? |
| *Rattus tunneyi* | locally extinct |

| | |
|---|---|
| *Rattus fuscipes* | common |
| *Phascogale tapoatafa* | uncomm/rare |
| *Perameles bougainville* | locally extinct |
| *Myrmecobius fasciatus* | rare-lg decline |
| *Hydromys chrysogaster* | sparse to common |
| *Isoodon obesulus* | common-decline |
| *Pseudocheirus occidentalis* | rare/endangered |
| *Dasyurus geoffroii* | rare/endangered-decline |
| *Potorus tridactylus* | rare-decline |
| *Lagorchestes hirsutus* | locally extinct |
| *Bettongia penicillata* | rare-decline |
| *Bettongia leseur* | locally extinct |
| *Lagostrophus fasciatus* | locally extinct |
| *Trichosurus vulpecula* | declining-some range decline |
| *Setonix brachyurus* | common-small range decline |
| *Onychogalea lunata* | extinct |
| *Petrogale lateralis* | locally extinct, >90% decline |
| *Tachyglossus aculeatus* | common |
| *Macropus eugenii* | common-decline |
| *Macropus irma* | possibly decining (#'s) |
| *Canis lupus* | rare?-large decline |
| *Macropus robustus* | ? |
| *Macropus fuliginosus* | abundant |

**NOMADIC BIRDS IN SOUTHCENTRAL AUSTRALIA**

| Species | Mass |
|---|---|
| *Acanthiza reguloides* | 0.87506 |
| *Certhionyx niger* | 0.89209 |
| *Dicaeum hirundinaceum* | 0.90309 |
| *Pardalotus punctatus* | 0.96379 |
| *Daphoenositta chrysoptera* | 1.07555 |
| *Poephila guttata* | 1.10992 |
| *Zosterops lateralis* | 1.11059 |
| *Melithreptus brevirostris* | 1.16435 |
| *Cheramoeca leucosternum* | 1.17026 |
| *Phylidonyris albifrons* | 1.25527 |
| *Chrysococcyx basalis* | 1.35793 |
| *Certhionyx variegatus* | 1.41414 |
| *Melopsittacus undulatus* | 1.4624 |
| *Artamus cinereus* | 1.54407 |

| | |
|---|---|
| *Geopelia cuneata* | 1.55023 |
| *Artamus cyanopterus* | 1.60206 |
| *Turnix velox* | 1.61278 |
| *Neophema elegans* | 1.63347 |
| *Glossopsitta porphyrocephala* | 1.64147 |
| *Acanthagenys rufogularis* | 1.64345 |
| *Neophema chrysostoma* | 1.65321 |
| *Glossopsitta concinna* | 1.87967 |
| *Nymphicus hollandicus* | 1.94748 |
| *Coracina novaehollandiae* | 1.96988 |
| *Trichoglossus haematodus* | 2.08636 |
| *Anthochaera carunculata* | 2.09691 |
| *Coracina maxima* | 2.12574 |
| *Falco cenchroides* | 2.19312 |
| *Accipiter cirrhocephalus* | 2.25527 |
| *Elanus notatus* | 2.39794 |
| *Falco longipennis* | 2.40312 |
| *Cacatua roseicapilla* | 2.51248 |
| *Corvus bennetti* | 2.58092 |
| *Circus assimilis* | 2.62325 |
| *Calyptorhynchus lathami* | 2.63347 |
| *Accipiter fasciatus* | 2.70757 |
| *Tyto alba* | 2.71892 |
| *Cacatua sanguinea* | 2.72016 |
| *Falco berigora* | 2.73997 |
| *Corvus mellori* | 2.75358 |
| *Burhinus magnirostris* | 2.83554 |
| *Falco subniger* | 2.89515 |
| *Haliastur sphenurus* | 2.90309 |
| *Calyptorhynchus funereus* | 2.90363 |
| *Milvus migrans* | 2.91751 |
| *Hieraaetus morphnoides* | 2.92376 |
| *Aquila audax* | 3.54407 |
| *Dromaius novaehollandiae* | 4.4936 |



| Species | Mass |
|---|---|
| *Certhionyx niger* | 0.89209 |
| *Dicaeum hirundinaceum* | 0.90309 |
| *Ephthianura tricolor* | 1.02407 |

| | |
|---|---|
| *Ephthianura albifrons* | 1.07918 |
| *Phylidonyris albifrons* | 1.25527 |
| *Phylidonyris nigra* | 1.26245 |
| *Phylidonyris novaehollandiae* | 1.30103 |
| *Certhionyx variegatus* | 1.41414 |
| *Chrysococcyx osculans* | 1.45818 |
| *Melopsittacus undulatus* | 1.4624 |
| *Artamus personatus* | 1.54937 |
| *Geopelia cuneata* | 1.55023 |
| *Turnix velox* | 1.61278 |
| *Cinclosoma castanotum* | 1.8654 |
| *Coturnix australis* | 1.97373 |
| *Coracina maxima* | 2.12574 |
| *Lophoietinia isura* | 2.69984 |
| *Ardea pacifica* | 2.81291 |
| *Threskiornis spinicollis* | 3.25527 |

[1] Italy bird data includes latin name (Species), abundance (Abun.), body mass (Mass), gap statistic (RGS), lump membership (Lump), population trend (Trend) and status. Body mass estimates are from Dunning (1993).

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## BIOGRAPHICAL SKETCH

Craig R. Allen was born on February 20, 1963, in Berkeley, California. Soon thereafter his family moved to Madison, Wisconsin, where he spent nearly 30 years. He spent many summers on his grandmother's farm in Alabama, tormenting fire ants, and vice versa. Craig also spent three years living in England and the Netherlands before beginning studies at the University of Wisconsin, Green Bay. After realizing the utter futility of making a living producing creative writing, and becoming disenchanted with the fields of geology and forestry, Craig quit school and started a chimney sweeping business with friends in Madison. Not surprisingly, this endevour drove Craig back to the University of Wisconsin, where he both met his wife Patty and received a B.S. degree in biology in 1989. (Patty read this page, and suggested I add to the previous sentence "...his beautiful, talented and witty wife, Patty.") Craig completed a Master's degree at Texas Tech University three years later before moving to Gainesville, Florida where he began his doctorate studies in the fall of 1993. Craig and Patty now have one son, Reece Hunter, who asks as I write, "why are you writing that?"

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

W. M. Kitchens, Chair
Associate Professor of Wildlife Ecology
and Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

S. R. Humphrey
Professor of Wildlife Ecology
and Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

M. P. Moulton
Associate Professor of Wildlife Ecology
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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December, 1997

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